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SHUTTLE RECOVERY PROGRAM

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDREDTH CONGRESS

SECOND SESSION

ON

OVERVIEW OF THE SHUTTLE RECOVERY PROGRAM

FEBRUARY 16, 1988

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OVERVIEW OF THE SHUTTLE RECOVERY PROGRAM

TUESDAY, FEBRUARY 16, 1988

U.S. SENATE,
SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, D.C.

The subcommittee met, pursuant to notice, at 9:35 a.m. in room SR-253, Russell Senate Office Building, Hon. Donald W. Riegle [chairman of the subcommittee] presiding.

Staff members assigned to this hearing: Marty Kress; John Graykowski, professional staff members; and Pete Perkins, minority professional staff member.

OPENING STATEMENT BY SENATOR RIEGLE.

Senator RIEGLE. The committee will come to order.

We have some very distinguished witnesses with us this morning. We will introduce them in due course.

It has now been two years since the profound loss of the Challenger spacecraft and its seven person crew. In the time since, many important and fundamental changes have taken place at NASA.

The recommendations of the Rogers Commission are being implemented. Many of those changes involve key improvements in the shuttle system designed to make it safer. As we complete that process, NASA has now begun its flight countdown, as we prepare for America's return to space, the next manned launch of the shuttle.

The target date for launch is now August 4, some five and a half months from today. Many thousands of people are at work as we meet here, and they are working on a seven day a week schedule to meet that timetable, and to do so with a maximum degree of safety and reliability that we can achieve.

It is important to note that prior to the Challenger accident NASA had a remarkable record of a quarter century of manned space flights without a single life being lost in flight. That included six manned trips to and from the moon.

The space shuttle and its supporting system is one of the most complex engineering projects ever undertaken. It is inherently dangerous, a fact that is well known to our astronauts and their families.

And while our best efforts can reduce the risks involved, when we fire manned rockets with 5.2 million pounds of thrust we fully test the outer limits of our scientific capability and our human skill.

Not surprisingly, as the shuttle system has been revised problems have arisen along the way. Rigorous testing procedures have identified areas of difficulty needing additional work. Those adjustments and modifications are now being made.

Today we are going to ask those representing NASA and others charged with arm's length evaluation of those efforts to report on the status of the work that is being done to enable us to return to flight.

We want our witnesses today to tell us frankly and directly what problems remain, how they are being addressed, and whether they have the resources they need to do the job right. We want their assurance today that safety will always overrule flight schedules and that if further time is needed to ensure greater safety that the launch date will be moved accordingly.

One of our most important witnesses today is Commander Hauck, the flight commander of the next shuttle mission. The subcommittee is encouraged to see that the astronaut office has been involved directly in all phases of the redesign effort and to note this new closer working relationship between the people that build and operate the shuttle with those that have to fly it.

I just want to conclude with this thought, that I would hope that from this hearing this morning as we review where we are, as we come down through this countdown to taking America back into space, that the message will go out of there across our own country and around the world that, as far as manned space initiatives are concerned and space leadership, that America's confidence and its nerve and its commitment are alive and well and on schedule.

Senator Hollings.

OPENING STATEMENT BY THE CHAIRMAN

The CHAIRMAN. Mr. Chairman, a man can work a whole lifetime trying to establish a good reputation, but is only takes a moment to lose it. And if you do lose it, it takes an eternity to reestablish it.

The Challenger disaster was a national tragedy. We lost seven able bodied crew members, a space shuttle, our national launch capability, and NASA lost its reputation as the hallmark of safety, reliability and quality assurance.

Since the accident, NASA has been working feverishly to regain its reputation. But this has not been an easy task. In days gone by, a NASA pronouncement that they had analyzed a problem and found the solution would have ended debate of the issue. Today, that is not the case. Each problem, each flaw, each test, each decision, is closely analyzed and scrutinized by the press, the Congress, and others outside the system.

I suppose that this is the price NASA must pay for a tragedy like Challenger. And to some degree, the increased scrutiny is a good thing because it forces NASA and the contractors to go the extra mile. But at

some point, confidence in NASA must be reestablished. However, it is quite clear today that this will not occur until the tests have been run and the space shuttle successfully flies. If NASA performs, confidence will be regained over time.

But if NASA is to perform successfully, every person associated with this program must do their job and do it right. The space shuttle is as good as the people, the hardware and the process.

During the course of the last few months, there have been problems—a boot ring failed, welds were not done to specifications, the wrong bolt was used on the nozzle joint. And each of these problems has further raised the flag of concern.

Today, we're going to look at some of these problems and discuss what NASA is currently doing to solve them. We're also going to assess the return of the space shuttle to flight status and the milestones that must be met before Discovery flies.

To assist in this effort, we have the key members of the NASA space shuttle team, including Captain Rick Hauck, Commander of the next mission, and the principal spokespersons for the two primary oversight groups—Dr. Stever, of the National Research Council, and Mr. Parmet of the Aerospace Safety Advisory Panel.

The major goal of today's hearing is to assess the status of the NASA's return to flight activities, to make sure safety is the agency's hallmark, and to be sure that, the NASA team is headed in the right direction—lower earth orbit.

If there's one message I want this hearing to convey to our witnesses today, it's that we're here to ensure the return to flight of a safer, more reliable space shuttle and we're willing to work with NASA towards that end.

If there's one message I hope to leave the room with today, it's that we got the right team with the "right stuff" in place and doing the job for NASA.

Thank you, Mr. Chairman.

Mr. Thompson, we brought you on to get us going and going fast. We induced you to come back from Princeton, and I want to hear particularly from you a progress report.

I have been reading and studying this matter. I never did like the Rogers Commission report, with nonsense that everybody was at fault. I believe in fixing responsibility and I think it should have been fixed.

With that in mind, I wonder about Morton-Thiokol. Yes, they might have the best technical proposal, but do they have the best technical management? Do they have the best technical production?

If you read my newspaper you do not get that impression. In fact, I did not realize that our colleague over on the House side, Chairman Jack Brooks, had asked for a study a week before we did. But Senator Riegle and I joined together asking the General Accounting Office to get back in there and look into Morton-Thiokol and find out exactly what was going on.

I do not believe in nagging and picking. If you assign the responsibility, let them do it. And in that spirit, I have been backing Dr. Fletcher.

But now, after all of this time has passed, I am beginning to wonder, with all the different tests and things going awry, whether or not we do have quality management and quality production at Morton Thiokol.

I know they had the best technical proposal, because they had the best experience there. But I do not know whether they have gotten the message or not, and that is what is disturbing me, because there is no reason for Captain Hauck to be a daredevil. He has got other things to worry about.

And we were going to make it safe, but at the rate we are going he is not going to get up there ever. And I want you to tell us what is going on up there.

Thank you, Mr. Chairman.

Senator RIEGLE. Thank you, Chairman Hollings.

I have a statement that Senator Pressler would like to have included in the record.

[The statement follows:]

OPENING STATEMENT BY SENATOR PRESSLER

Today's hearing of the Subcommittee on Science, Technology, and Space focuses on what is unquestionably the single most important short-term objective of our civil space program—the recovery of the Space Shuttle for its first mission since the Challenger accident of over two years ago. Mr. Chairman, I commend you for calling this hearing, as many important milestones have been met and other significant events have occurred since this Subcommittee last reviewed the Shuttle program. This hearing will allow the Subcommittee to review thoroughly not only the results that have brought us this far, but also the job that remains.

Certainly, the cornerstone of this recovery program has been the redesign and testing of the solid rocket motor. And while the first two full-scale firings have, by most accounts, been successful, there are certain dimensions of the Shuttle recovery program that warrant continued and closer inspection. For instance, recently discovered problems, such as weld flaws and the use of incorrect bolts on the SRM, raise certain concerns that must be addressed. And while I recognize that in a program of this complexity certain problems will arise, we must make every attempt to minimize the impact of these problems and ensure that they do not compromise flight safety.

It is worth noting at this time, the positive effect that the National Research Council oversight panel has had on the redesign of the solid rocket motor. This panel has provided excellent technical direction and has served as an effective "sounding board" for NASA and its contractors. The Subcommittee is fortunate to have today the Chairman of this oversight panel, Dr. Guyford Stever, to comment on NASA's responses to date to the recommendations of his panel, as well as on the remaining milestones and risks in the redesign program.

And concerning the NRC recommendations, I, for one, am pleased that NASA has decided to adopt, what I consider, one of the NRC's most significant recommendations—that of increasing to five the number of full-scale, full-duration firings. Such a decisions will not only lead to an increased technical understanding of the redesigned solid rocket motor, but will also boost our confidence in this new design when we do resume flight operations.

NASA should be commended for its attention to safety as a foremost priority in this Shuttle recovery program. Of course, the cost of incorporating more safety into the Shuttle and the solid rocket motor is usually measured in additional launch delays and resource requirements. Yet, we have observed on several occasions, NASA's willingness to delay the launch to incorporate additional safety measures. Such decisions are not easy to make, and yet NASA has shown considerable courage in making these difficult decisions.

Many of the issues discussed today will take on a even greater importance as we approach the target launch date of August. Certainly, this upcoming launch will be scrutinized and examined more carefully, both by NASA and the rest of the world, than any other launch in the history of our space program. For this and other reasons, I am confident that this mission will succeed. The challenge, however, will be in sustaining over a much longer period of time this commitment to safety that has characterized this recovery program.

Mr. Chairman, I believe that I speak for all of the Members of this Subcommittee in stating our desire to work with NASA in a spirit of cooperation as we prepare for this next launch. Because we recognize the value of our space program, we are understandably anxious to return the Shuttle to flight. Yet, we must appreciate the difficult job of balancing the need to return to space with safety.

With these thoughts in mind, I am pleased to welcome Mr. Aldrich and his colleagues from NASA, Dr. Stever of the National Research Panel, and Mr. Parmet of NASA's Aerospace Safety Advisory Panel. Their testimonies will give the Subcommittee new insight into the important issues surrounding NASA's return-to-flight.

Senator RIEGLE. Let me make two other announcements at this point. Admiral Truly, who had intended to be with us this morning, is very sick with the flu and sends his regrets. And so in his place Mr. Arnie Aldrich will be the lead witness for NASA.

I should also note—and this is a sad note—that yesterday Dr. Richard Feynman, who was a Nobel laureate and a member of the Manhattan Project, and of course a very distinguished member of the Rogers Commission, and who made a very important contribution to that Commission's work, passed away. So we will remember his contribution in many ways, but very importantly in terms of his work to try to understand the shuttle, the Challenger accident.

So with that, let me now introduce our witnesses. In our first panel we have, as I have said, Mr. Arnold Aldrich, who is the director of the National Space Transportation System, who will be the lead witness for NASA today. He is accompanied by Mr. J.R. Thompson, who is the Director of the Marshall Space Flight Center, and also Captain Frederick Hauck, who is the commander of the next shuttle flight.

And it is a very distinguished group and we would like to hear your testimony and opening statement now, please.

STATEMENT OF ARNOLD D. ALDRICH, DIRECTOR, NATIONAL SPACE TRANSPORTATION SYSTEM, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION; ACCOMPANIED BY J.R. THOMPSON, DIRECTOR, GEORGE C. MARSHALL SPACE FLIGHT CENTER; AND CAPT. FREDERICK H. HAUCK, COMMANDER, STS-26

Mr. ALDRICH. Thank you, Mr. Chairman.

I would like to reiterate that Admiral Truly made a valiant effort to appear here today, but was just not able to be here. So we will do our best to answer your questions and provide the information you are seeking.

I am pleased to appear before you today to discuss our progress toward restoring our nation's access to space. It has been almost 25 months, as you pointed out, Mr. Chairman, since the Challenger accident, and we have made significant advancements toward returning space shuttle to flight readiness.

Following the accident, there was a broad period of self-introspection within the space shuttle program and within NASA: what things were wrong, what needed to be fixed. And we have driven ourselves to re-review every system, every process, and to make changes as required.

Today there is an upswelling of confidence within NASA and within the shuttle team that we are nearing the end of this process. The shuttle program has been totally reassessed and strengthened and important changes have been made in many areas to improve our processes and to provide additional safety margins.

We are now approaching the time when the space shuttle will again be ready to fly. Discovery has completed essentially all of its processing and modernizations for first flight, and Atlantis and Columbia are in preparation for STS-27 and STS-28.

The three space shuttle main engines for STS-26 have completed their acceptance tests, have been delivered to Florida, and have been installed on Discovery. The solid rocket motor and solid rocket booster elements, however, are still our critical path for returning to flight.

In past months we have had two highly successful full-scale firings of the solid rocket booster, DM-8 and DM-9. These tests have provided us with high confidence that our solid rocket motor major redesigns in the case-to-case joint and case-to-nozzle joint and the nozzle itself are sound and the redesign margins are there as intended.

However, a failure of a nozzle component called the outer boot ring late in the DM-9 firing on December 23rd of last year has caused us to adjust our projected launch schedule a second time during this standdown period, from June to August of 1988.

Fortunately, we had proceeded with an alternate design for this outer boot ring, as the National Research Council has encouraged us, and it performed successfully earlier during the DM-8 firing in August of 1987.

Thus, we are reconfiguring our flight and major test motors to the DM-8 boot ring configuration, and we will be delivering aft segments to KSC for STS-26 on March 21st and March 14th in this configuration to support the August launch.

Three additional full-scale tests of the solid rocket motor, however, will be performed to complete our certification and testing, both of our SRM redesigns overall and of the outer boot ring itself.

The QM-6 motor firing is scheduled for April 12th. It will be an all-up flight-configured solid rocket motor, and it will include flaws in both the case-to-case and case-to-nozzle joints to demonstrate manufacturing flaws that could be incurred in our build process.

The QM-7 test will be on June 9th of 1988. It will be in the new test stand at Morton-Thiokol, which can simulate structural dynamic loading in flight, in addition to the motor firing process itself.

And finally, a new motor called PVM-1 has been added to our return to flight sequence, and will be fired on July 6th. And this motor, although fully flight configured, will be flawed in an even greater extent to provide pressure-assured flaws to our primary O-ring systems to verify our design redundancy that we have incorporated for margin.

Other major milestones for launch: Discovery will move out of the OPF on April 18th, to be ready for stacking with the external tank and the rest of the stack on May 15th. We will do a flight readiness firing of the entire shuttle main propulsion system on June 15th, and stress the entire launch team for a complete all-up countdown to flight activity. Our internal working date for launch, as you pointed out, is August 4th.

In summarizing my testimony, I would like to read the final paragraph from Admiral Truly's formal statement, which I think summarizes his view of our posture at this point in the return to flight process:

"These past two years have been difficult ones. The NASA/contractor team has not only had to cope with the emotional impact of STS-26 and the subsequent, often harsh, criticism, but has undertaken an intensive self-examination of our products and our processes.

"This outstanding group of individuals has responded magnificently. Managers, engineers and astronauts are working together to the same goal, the safe and reliable flight on the earliest day that we are ready. The result will be one of which all of us can be proud and will restore our nation's confidence in our greatness.

"The schedule is success-oriented and remains tight, but our confidence grows with each test and each milestone represents a significant stride toward returning our fleet of space shuttles to service."

I would like to submit Admiral Truly's formal testimony and answer your questions with JR and Rick as you desire.

[The statement follows:]

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PRESENTED BY WITNESS

Statement of

Richard H. Truly
Associate Administrator
Office of Space Flight

National Aeronautics and Space Administration

before the

Subcommittee on Science, Technology and Space
Committee on Commerce, Science and Transportation
United States Senate

Mr. Chairman and Distinguished Members of the Subcommittee:

I am pleased to appear before you today to discuss our progress toward restoring our nation's access to space. We have made significant advancements since the Challenger accident and, although there remains much to do, I believe you will agree our efforts have been constructive and productive. We are on the right track.

The effort to redesign the Solid Rocket Motor (SRM) has been, and remains, the driver behind the return-to-flight schedule. Three full-scale firings have been conducted during the past year and three more are scheduled between now and mid-July 1988. Performance of both the redesigned field joint and the case-to-nozzle joint have been superb. Redesign joints were tested and verified on two tests, Development Motor (DM) -8 and DM-9, August 30, 1987, and December 23, 1987, respectively. We have experienced no blow-by of gasses on the redesign joints, even to the primary "O" ring seal. Of course, more observations will be made and data collected on the three upcoming full-scale tests, but our confidence in success is very high.

Another recent area of scrutiny in the SRM redesign is the outer boot ring in the nozzle assembly. Distress to this area was seen on several Shuttle flights, and we decided it must be improved as part of the SRM redesign effort. We developed two designs along parallel paths. One was tested satisfactorily during the DM-8 firing. The second was tested during DM-9 and, as you know, failed. In selecting the DM-8 version for flight, we incur a delay in delivery of the aft SRM segments to Kennedy Space Center (KSC), Florida. Launch of STS-26 is now projected to be in August 1988.

I hasten to put the outer boot ring in proper perspective. The role of this element is to protect the nozzle flex bearing for reuse. It has always fulfilled this objective --- in every flight, and even on the DM-9 test. In this case, the failure actually occurred seconds after the motor burn completed and was not a flight safety issue. Our objective in the redesign is to achieve a greater margin. I also believe the redesign team is to be commended for developing alternative designs along parallel paths, consistent with recommendations by the National Research Council. We might have experienced a delay of a year or more, had there not been an alternate design available at this juncture.

The SRM will undergo further extensive testing prior to STS-26, including three full-scale firings. The first of these is Qualification Motor (QM) -6, planned for April. It will contain deliberate, manufacturing-type flaws to verify performance of the redesign. A deliberate "blow-hole" will be introduced in the case-to-nozzle joint. Blow-holes can occur if small amounts of air, trapped in the system during the assembly process, escape through the polysulfide adhesive. We, in fact, experienced an unintentional blow-hole in the case-to-nozzle joint during the DM-9 test. In that instance, the wiper "O" ring, which is not part of the seal in this joint, showed no erosion or other distress. This test result confirms our analysis that the situation is not harmful even if it does occur. The intentional QM-6 blow-hole will provide additional baseline data on the phenomenon in a way which may be measured with greater precision. QM-6 will also contain a "wave," or deliberate "J" seal opening in the case-to-case joint. The purpose of this flaw will be to demonstrate that the joint design performs satisfactorily in the presence of this condition.

The second remaining SRM test will be QM-7 in June and will not be deliberately flawed. The final scheduled full-scale test will be Production Verification Motor (PVM) -1 in July. Both case-to-case field joint and case-to-nozzle joint will be flawed in such a way as to assure pressure to the primary "O" ring and demonstrate the redundant characteristics of the design.

All three Space Shuttle Main Engines (SSME) have completed acceptance testing, been delivered to KSC, and are installed in Discovery. Inspections have detected flawed electron beam welds in some high-pressure fuel turbopump first stage rotor (fishmouth) seals. The cause is mistracking and misregistration during the welding process. Since the flight pumps cannot be inspected in place, three pumps with proper welds are being readied for shipment to KSC. Replacement of the flight units is not expected to impact the flight schedule.

A newly-developed technology for ultrasonic inspection of welds has been employed to check the integrity of the SRB aft flight skirts. This technique has cleared the first set of skirts for flight.

We have implemented a design change to eliminate a concern on the orbiter/external tank 17-inch disconnect latch mechanism. The latch mechanism was designed into the valve to preclude inadvertent closure of the flow control device during powered flight. Subsequent measurements have revealed flow-induced deflections of the latch shaft resulting in interference and rubbing contact. Modifications are in work to limit rotation of the latch actuator and eliminate the rubbing. This field modification should be available in mid-March.

We anticipate certification of the redesigned gaseous oxygen flow control valve in ample time for STS-26. The prior design routed oxygen through a tortuous path and a test anomaly was encountered at White Sands Test Facility, New Mexico, in July 1987. The redesign improves the materials and geometry of the valve to gain greater safety margin. The new valve has been installed in Discovery, and qualification testing started in February 1988.

Modifications to the ingress/egress hatch are being incorporated into Discovery for STS-26 to facilitate emergency crew egress during non-powered flight. To provide wing clearance for the crew, two options are being examined. Both tractor rockets and an extendable pole technique are being developed and flight tested with a decision expected in April. Crew escape during powered flight is being studied for possible implementation much later in the program.

Excellent progress is being made on our Failure Mode Effects Analysis, Critical Items List, Hazard Analysis, and Design Certification Reviews. Although considerable work remains to be done, we are confident of completion without impact to launch schedule plans.

Our schedule of major milestones for STS-26 is built around delivery of the flight aft SRM segments to KSC. Movement of Discovery from the Orbiter Processing Facility to the Modification and Refurbishment Facility is scheduled for April. In May, Discovery will move to the Vehicle Assembly Building for mating with the external tank and SRMs. Rollout to the launch pad and the flight readiness firing of the SSME is scheduled for June, and launch of STS-26 is planned for August.

These past two years have been difficult ones. The NASA/contractor team has not only had to cope with the emotional impact of STS-26 and the subsequent, often harsh, criticism, but has undertaken an intensive self-examination of our products and our processes. This outstanding group of individuals has responded magnificently. Managers, engineers, and astronauts are working together to the same goal -- a safe and reliable flight, on the earliest day we are ready. The result will be one which makes all of us proud and restores the nation's confidence in our greatness. The schedule is success-oriented and remains tight. But our confidence grows with each test, and each milestone

represents a significant stride toward returning our fleet of Space Shuttles to service.

I am joined here today by Arnie Aldrich, Director of the National Space Transportation System; J. R. Thompson, Director of the Marshall Space Flight Center, Alabama; and Rick Hauck, Commander of STS-26. We are pleased to answer any questions you may have.

Senator RIEGLE. We are pleased to have that.

Do either of the two of you want to make a statement at this time?

[No response.]

Senator RIEGLE. Senator Kerry, did you have an opening comment you wanted to make?

OPENING STATEMENT BY SENATOR KERRY

Senator KERRY. Mr. Chairman, as we begin today's hearing I want to commend you for moving ahead in a timely fashion with these recovery oversight hearings and I would like to thank today's witnesses for participating in the hearings. Their professional expertise and personal dedication to America's space program are extraordinary and we are all in their debt. I hope that they will take back to their own communities the sincerity of our appreciation.

All of us share the common purpose and dedication of restoring America's space program to full, safe and reliable flight. We also share an understanding that this is an enormously difficult, challenging and I might add, costly task.

As the difficulties seemingly multiply with each passing day, we are reminded how very dangerous human space flight is. It is because of that very danger that the most important mission we have before us remains safety. With two years on the ground and the pressure to fly building each day, it is difficult to stay focused on safety. But it is paramount.

No one of us can answer that question, "how safe is safe" and no one of us can guarantee absolute safety. Neither can we try to redraw or recreate levels of safety in midcourse. If we fall onto that treadmill, we will never fly. Instead, we we will spin wheels over and over an ever changing terrain. We must move on. But, we must do so responsibly.

I look forward to today's testimony because few have as much at stake here as today's witnesses so their measure of safety and where we are on the yardstick is critical. We must also remember that public confidence in America's space program and space industry is on the line as we return to flight. Our citizen's want to know that we have done out best to guarantee the lives and safety of our astronauts in this and subsequent flights

They want to know that despite the pressures to meet those launch windows for Magellen and Galileo we will err on the side of caution because the future of a generation of space science and scientists rides on this process.

We are anxious to look down again at the earth, to look out at the universe, to see through the Hubble Space Telescope, return to the

moon, set out for Mars and begin work in zero gravity. But we must get there with confidence.

I have confidence that we will meet the tough standards of safety and technological advance which have been set out and I have confidence that we will do it with wisdom. We must also do it with openness and good faith. We are learning from this painful process. We are building. We are moving forward. And I am sure that with a Massachusetts Connander we are moving safely back into flight.

Senator RIEGLE. Mr. Thompson, you and I have had some good blunt discussions in the past, and you have a reputation for being direct and to the point, and that is very helpful. Not that the others do not, but we have had occasion to test that over time.

I would like you to initially take us right to the area of the problems that we have at the moment, the ones that were identified in the previous test firings. You mentioned some here with respect to the nozzle and the boot ring and so forth.

I would like you to be very forthright in telling us precisely what problems remain that you are working on now that are a matter of concern, what is being done about them, and what the picture is.

And I would like to hear from all three of you, actually, on that issue, because that is critical as far as I am concerned. So who would like to start?

Mr. ALDRICH. Let us see. I believe the two most significant problems we have been working are in the solid rocket motor area, with the outer boot ring and with the hozzle bolts JR is prepared to describe each of those and where we stand today.

Senator RIEGLE. Mr. Thompson, why do you not tell us about those problems, how serious we are, and what we are doing about them?

Mr. THOMPSON. All right. And if I could, I would like to use some visual aids.

I have a couple of viewgraphs I would like to use first to give you an overall orientation of what I am going to be talking about. There are two detailed sketches here for your close look, and then I have ome hardware here that I would like to bring up and show you.

Later on I would like to make some comments about the overall progress of the solid rocket motor, but first I would like to go straight to the heart of your question and talk about the problem areas. And that deals with the solid rocket motor nozzle.

[Viewgraph.]

This is not a good picture. It does give you an overall view, though, of the size of this motor. A little later on I am going to be talking about a cross-section down in this area that describes the boot ring that you cannot see well here.

A lot of the carbon parts are sacrificial. They do char and erode during the burn. That is very normal.

There is a bolt in here that I will be discussing in detail, and I believe over the weekend in the media there was some discussion about ply lifting down in the aft exit. I would like to discuss that and where we are.

A few dimensions on the overall nozzle. It is about 18 feet long from the forward end until the end of the aft exit cone. And I mentioned it is basically lined with carbon, which is sacrificial.

[Viewgraph.]

Going right to the cross-section that I mentioned, again the centerline of the motor is up here, and this is a big ring that goes all the way around. And when the nozzle steers plus or minus seven degrees in any direction, it pivots about this point.

This is a flex bearing which is a combination of rubber and metal parts that allow it to move, so the whole nozzle can be steered to plus or minus seven degrees.

The boot ring is right here. This is a rubber boot. There are seven plies in it. In a typical motor firing, either three or four of those plies will erode away.

Some major parts of this boot ring are outlined right here. Again, it is sacrificial and it will char and erode. These are all carbon parts here, as I mentioned, including on to the aft exit cone.

The only purpose of this boot and boot ring and this cowl is to protect this flex bearing. This is a reusable part. We do have some money in it, so we want to recover and reuse it.

The purpose then is to keep the heat—and by the way, you are talking about temperatures outside of the boot ring and in the contour of the aft unit of the motor would come down here and go forward—the propellant interface at ignition would come up to about this point, and there are about four inches between this outer boot ring and the propellant interface.

The environment here is about 5,000 degrees Fahrenheit, so we want to keep heat off of this flex bearing.

During firings and launches preceding the 51L accident, in looking back throughout the whole solid rocket motor, where we made a number of changes, but in this boot ring we saw that, because of the way we had laid up the plies, we were getting small pieces or chunks coming out.

And I will show you in some of the physical hardware in a minute exactly what I am talking about. But during this down time we wanted to go back in and add some margin in this area.

Basically, we added about three-quarters of an inch in thickness in this outer boot ring, some additional meat on this cowl to make sure that we had plenty of margin as this part erodes and chars back during the motor firing.

We wanted to make the change in this area, and as I think was mentioned earlier, we wanted to have a parallel design because we were making a change. And I will talk about that a little more in a moment.

To get right to the heart of it, the change that we made and tested on DM-9 was more radical than what we had been flying. We had baselined that for the flight program. After the DM-9 firing, then about a half of this boot ring, popped off.

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It is very clear from the data that the boot ring just—this part right here—separated from the boot. And if that occurred in flight, it would allow hot gases to get back in here and start it eating into the margin in that flex bearing.

The phenomenon did occur after the motor firing, but we did not see enough margin in this part. We tested one sample even after the firing during a gimbal cycle. It did come off. We did not like what we saw, so we stopped and we made a change.

We have fallen back to what we successfully tested on DM-8. DM-8 has the same dimensions. It was made thicker from what we had been flying. It was less of a deviation from what we had been flying.

In looking at the boot ring after the DM-8 firing, it looked in good shape. The question always come up, well, why did you go to the DM-9? At that point we had already committed to the DM-9 configuration, which is called the involute design.

At the time we made that decision we had not seen the results of DM-8. So in retrospect, I wish we had committed to the DM-8 configuration for the flight program.

We started this review back in the spring time. Both NASA engineers and the Thiokol engineers reviewed the two concepts. The NASA engineers, including myself, preferred the DM-9 configuration conception, because in the involute design we would be increasing the length of the bond line. That is always the weak link in trying to make sure that we do not have any delamination in getting hot gas back to this joint.

The Thiokol team preferred the more modest advancement, and that is just a deviation and a variant of what we had been flying, adding the additional thickness. But at the final analysis, we collectively all agreed that the DM-9 configuration had the superior potential and therefore we baselined that for the program.

Unfortunately, it did not work or it did not have the margin, as I indicated earlier. And we are going to fall back to the DM-8 configuration. Everything we have seen to date has plenty of margin to fly and I believe very safely.

Let me just make another point. This system has to work at motor ignition. We want to make sure that we do not get hot gas in this flex bearing. It cannot sustain the two minutes of burn and still not degrade so that you would have a major failure.

But it is our judgment, looking at the analysis, that if this part does leak and you get hot gas back in here on the latter half of the mission, you would probably not be in a position to reuse this part, but certainly it would not be criticality 1.

But I take no comfort in that. It did not perform as designed, we did not have the margin in there we anticipated—we took the two months in launch schedule and I think made the correct decision.

I would like to show you a few parts from both the DM-9 and the DM-8 configuration in a moment. But while I have got this chart up, I would like to highlight two other areas that I am going to be talking about. And that is the bolts here, where we have got a configuration that is not good engineering practice, and I will discuss that; and then

some delaminations that occurred in our ETM firing in late spring, early summer.

And we have a reason for that. It is a process control issue, but that occurs in the last ten feet of the aft exit cone, and I will have some hardware to show you there.

Let me leave this chart up now and come up with the hardware and show you exactly what I am talking about. Let me start with the DM-8 boot ring, and you can see the orientation is just backward. This is the cowl, this is all carbon.

What we had before, what we were flying, was a 35 degree wrap in the ply. And you can see even in the DM-8 configuration it tends to delaminate.

Senator BENTSEN. Excuse me. Would you mind turning the other way so we can see it, too?

Mr. THOMPSON. Sure. I'm sorry.

This is the configuration we tested on DM-8. Let me go back and show you exactly what we were flying before. If you look very closely, you can start to see some delaminations. This is at a 35 degree ply angle wrap. On the pre-51-L configuration, this wrap went all the way back to this bond line with the boot ring.

And we were seeing chunks of this kick out during the motor firing late in the burn, because we never had any hot gas get behind this cavity and attack that flex bearing in all of our flights, in all of our ground tests, including DM-9. That part has always been totally reusable.

But we wanted to have plenty of margin in this part, and so we were tending to get big chunks out and we wanted to fix that. What we put in was a backup strip. If you look close here, we changed the ply wrap so it is parallel to the centerline of the nozzle.

And you can see that the delaminations come up to that point and stop. So when I say the DM-8 configuration was a variant of what we were flying, that is what I am talking about.

But in seeing this delamination occur, we believe that the involute design, where it has got a wrap that is on the inside, and inside and out of the boot ring, over the long haul would give us a superior performance, and that is why we selected that. And it did not work.

This is the DM-9, same cross-section. You can see here that you tend to get delaminations. This happens to be on the right side of the motor. If you are standing on the aft end of the motor looking aft, the whole right side was in good shape. And this is a cross-section of that.

The left side for about 180 degrees separated and popped off in pieces, and it separated right at this bond line between the outer boot ring and the boot itself. After the test some soot did get behind this point. Had that occurred earlier in the firing, particularly very early, then it potentially could give us a criticality 1 failure.

Now, what happened? All of our analysis—we've still got some testing to go, but we think that on the left side of the motor you just need the separation to occur in one place, combined with the loads and the longer bond line. Once you start getting heat into that bond line, you

start building up what is called core pressure. And that is the internal pressure between the carbon plies. There is resin here. When you get heat to that, you will start building up internal pressure, and it will tend to separate.

So the very reason we went to the longer ply angle I think in the final analysis is what did it. Any load on here while you are weakening that bond line will tend to give you the separation. And on the involute design, once you start a separation you have no strength in this direction, and that is what finally let go.

We do get hot gas up to this interface, as you can see on this part here, and I will pass it around. But this part is actually eroded. It did stay together until about one second after the firing, and then we were going through a gimbal calibration, and again that left-hand side popped off and fell on the floor of the motor.

It is that lack of margin that we saw that we did not like. We do like what we see in the DM-8 boot ring. As I mentioned earlier, I wish we had baselined that. We were going after what we believed would provide superior performance over the long haul with this configuration.

This particular part looks good, but it has got to look good 360 degrees around, which it did.

The CHAIRMAN. When that occurred—you had so many successful flights. Has that been occurring all along? I mean, why all of a sudden now are we finding it is almost impossible to get the boot ring correct?

Mr. THOMPSON. We can get the boot ring. Let me go back to the DM-8 configuration, because it is a variant of what we were flying.

The CHAIRMAN. The question is, what you were flying seemed to work except for this one time. Now all of a sudden it always keeps coming apart. What accounts for that?

Mr. THOMPSON. Senator, it worked. We never got hot gas back here. But after the flight, on some of our nozzles—I believe there were a total of ten—we saw considerable chunking out here.

The CHAIRMAN. And had you been seeing that chunking out before the Challenger?

Mr. THOMPSON. We had seen the chunking out before the Challenger. It was never judged at that time, to be perfectly honest, to be a safety of flight issue. In this reassessment time, we collectively did not like the margin we saw and we wanted to take this opportunity to go in and fix it.

We started two ways, and that is to put this additional backup strip in here so that we can provide more thickness of the carbon. So it has been with us since day one. We believe what we have here now, this is going to continue to occur, this delamination.

And again, you are looking at a part at the end of burn. And so I believe, with everything we have seen, we have got a pretty good margin in this part if this does chunk out. Now, like we saw before, we have got about three-quarters of an inch of this backup strip in there that is still virgin, still protected, to give us a good bond line at this point and plenty of protection.

Senator KERRY. Can I just ask a quick question. You said earlier that some of the soot, et cetera, was breaking through there and going inside, which could create a criticality 1 failure.

Is that right?

Mr. THOMPSON. If it occurs, if it occurs very early in the firing.

Let me just further point out from here, we have got to—during the firings, max pressure is about 900 pounds per square inch out here. We do not want to collapse this boot ring and boot, and so we have 30 vent holes in here to allow pressure to get back here, so we stabilize that pressure.

But in none of these firings, pre-51-L, DM-8, or DM-9, have we ever gotten any erosion back behind here. On DM-9, after this half of this ring popped off we were starting to see soot on the back side of this rubber boot right here. We did not like that.

Senator KERRY. So what you are saying is, it has only been a DM-9 occurrence?

Mr. THOMPSON. Only on DM-9 have we had significant parts of that boot ring fall off. And I believe in retrospect, we made a change in that bond line. We tried to make it work for us, because you trap internal pressure there. As you heat up that bond line, the volatiles want to get out. They drive the separation apart. That is what got us, combined with the loads in that boot while we were gimbaling.

I might also mention one other thing. In DM-9 we provided the maximum gimbal profile we have to date in the program. I think as I mentioned in my testimony this time last year, all of our ground testing now is structured toward going to the max of the specification, making sure that we explore the limits.

We were swinging that nozzle from plus yaw to minus yaw very fast. We were doing it for a reason—to aggravate the chance of any recirculation of hot gas back at that case-to-nozzle joint. So we really exercised this part.

It was over and above the specifications. That is still good. We want to do that now on our subsequent motor firings as well, but we have never seen any hot gas back here, but we want to make sure that we have got plenty of margin in the part.

We did not want to be in a position where we fixed other parts of the motor. And frankly, they are going quite well. And then we were staring at this problem, pre-51-L, staring at it all during this two years, did not make some kind of corrective action. So we moved out on a corrective action. We bet on the wrong horse.

Senator RIEGLE. Let me just ask you to stay right there, Mr. Thompson. Captain Hauck, as you help think through this problem and you look at the data here and you look at this particular area, I would like to hear some comment from you as to the role that you folks are playing in this and how you view this problem and what we might know about that in terms of how you are interacting on other problems that have arisen here.

Captain HAUCK. Senator, we have had astronauts directly involved in monitoring the redesign effort since the accident. Specifically in the solid rocket booster area, we have had Hoot Gibson, Mark Brown, and now Steve Oswald assigned specifically to maintain insight into that.

And we are in a monitoring mode. We are not part of the decision-making process. We are part of the discussion process. Our opinions are sought and welcomed. J.R. Thompson and his organization, Alex McCool, head of safety at Marshall, have been very solicitous of our comments and our concerns.

This particular problem, as soon as it was discovered after DM-9, Steve Oswald was up at Morton-Thiokol to look at the hardware and has participated in many of the reviews of the redesign effort and the assessment as to how to cope with this.

So I think we have a very good insight and a very good opportunity to make our inputs into the decisionmaking process. Mr. Aldrich here, as head of the space transportation system, has made that opportunity very accessible. And I think that is indicative of the environment that we have found since the 51-L accident.

Senator RIEGLE. Let me ask you this. Hypothetically, if you and the others felt as you went down through this countdown period getting ready to fly again that some problem had not been solved adequately, at least to the collective judgment of the astronaut group, I assume you have a procedure by which you say, look, we want this changed, we want this fixed.

What would happen should that arise?

Captain HAUCK. I think we would get a fair hearing, Senator Riegle. Later on JR is going to talk about the bolt situation that came up, and I was pleased to have the opportunity to specifically talk with J.R. Thompson within the last few weeks to express some concerns we had about that and also to the program office.

It was not a contentious situation. We all have the concerns, and I guess what I would like to communicate is that I am very pleased with the open forum, and that is the important part, I think, is the communications link that we have.

And I am convinced that if we had a difference of opinion, we would get into that with a very deep technical discussion, which is an appropriate one. We in the astronaut office do not have detailed knowledge on every aspect of the program, and so when there is a problem that comes up we are learning at the same time that we are listening to the engineering judgment.

Senator RIEGLE. I think that is important, and we do want to go to this bolt issue shortly. But I would like to also say that, should there ever come a time when there is a very sharp difference of opinion that is not resolved in an orderly fashion, this subcommittee would like to know about it.

Captain HAUCK. I would appreciate that opportunity.

Senator RIEGLE. And would expect to know about it.

Let me ask my colleagues, on this matter that we have been discussing, are there any further questions on this item, or if not I'm going to ask JR here in due course to move on to the other problem areas that have been identified that are still being worked.

Are there further questions on this item?

The CHAIRMAN. I would just make the observation and that is, the chunking off did occur before the Challenger, but it was not considered a criticality 1 situation. Now you are considering that as a criticality 1 situation. You have already told us more in two minutes this morning more than the six month Rogers Commission did, and I appreciate it.

Senator RIEGLE. Senator Bentsen, did you have anything?

Senator BENTSEN. Only to comment that you are obviously never going to have a risk-free operation. You have to recognize and accept that.

I am also very impressed with the overstressing beyond what would be the normal operation in tryin to bring out any possible flaws. And so I'm very pleased with what I've heard this morning.

Senator RIEGLE. Did you want to go ahead now, Mr. Thompson?

Mr. THOMPSON. Yes. Just one other point I would like to leave you with on this. I mentioned that the DM-9 test, where we had the half of the ring pop off, was the most stressful test we have conducted to date in terms of swinging that nozzle.

We are going to conduct the remaining firings in exactly the same way. So that raises a question: Well, how do you know when you test the DM-8 configuration that it will not encounter the same thing?

It is our collective assessment that we have got plenty of margin in there and it will not. But the proof of the pudding is still in the test. And so we have still got to go through that wicket.

Before I take this chart down, let me use it as an entry of introduction to the bolt problem. First of all, let me describe the environment. I mentioned out here you've got between 5,000 and 6,000 degrees Fahrenheit hot gas. Through these 30 vent holes, then, we pressurize this cavity, which is the source of pressure to this RTV bond line, and then into this bolt, which is what we are trying to protect.

And I will show you a blowup of that detail in a moment. Because of view factor through this three-tenths of an inch diameter hole, and there are just 30 of them, then the environment in here is much reduced. It is about 2500 degrees Fahrenheit compared to the environment out here. There are not hot gases swirling around. It is fairly benign.

So fortunately, this is a very protected joint compared to any other joint in this nozzle. And on your sheets it is called out as joint number 5, and I would like to go to a detailed blowup of that and then I have got some pictures of rather the actual bolt in question in a moment.

[Viewgraph.]

Mr. THOMPSON. First of all, let me describe to you what we were flying. That is over on the left-hand side of the chart. It is on the left-hand side of the chart. This is the RTV. That is a room temperature cure. It is a buttering of a filler.

In all of our flights, we have never seen any charring of that RTV beyond about an eighth of an inch, which further substantiates that you are looking at a very protected environment. And again, the cavity that I showed you a moment ago that is enclosed by the boot ring is all in here.

We had a single O-ring right here, and then we had the same bolts that I will be describing in a moment, and they were threaded all the way to the head of the bolt. Let me state that at the outset. To date we have flown and ground tested over 4,000 bolts of this configuration, with the threads all the way to the bolt head, and have not had a problem.

In our redesign, we wanted to have redundant seals at all joints. And so we went to what you see on the right-hand side. We have got the same RTV, the same protected environment. It is considerably more benign than any other joint in the motor.

We added this O-ring and so we have got what we call the primary, as well as the secondary. We had to increase the thickness of this part in order to get that secondary O-ring in there.

We also wanted to verify that these O-rings on installation are tight, and so we had to build in a leak check port in this cavity so we could pressurize it to 900 psi, lock it up, and make sure that we do not have any leakage out behind this primary and through the RTV, through the secondary.

But we also want to make sure that we do not have any leakage down the shank of the bolt. And so we put this Stat-O-Seal at the bolt head, which I will now show you a part of.

Here let me get to the punch line of this whole thing, and that is, through an engineering error—and it was a dumb error—we did not put a shoulder on this bolt. In other words, we continued the threading all the way down to the bolt head.

So when we put the Stat-O-Seal on it, I will show you in a moment, it does not seal off the threads of the bolt at all. We are going to finally rely in the final analysis on the metal to metal seal that we have got there. And in my judgment, I will tell you right now, I think it is a very good seal.

We want to make the change at some point, but I believe personally we are okay for the next flight, with plenty of margin. Let me preface that remark by saying that we have not reviewed this totally with Dr. Fletcher, and so in my discussion you are going to hear come out my own position on this, but that has still got to be heard at the very top of NASA.

Senator KERRY. Can I ask a question?

Senator RIEGLE. Excuse me. Senator Kerry has a question.

Senator KERRY. I am just not sure I totally understood you. Are you saying that you are relying not on the threading per se, but on the secondary portion of that in order to get the adequate seal?

Mr. THOMPSON. Let me tell you how this whole sealing system works. If it works the way it has worked in all of our prior ground tests and in all of our flights, it will not even char the RTV. The hot gas, if it ever

gets there, is going to come right up to this surface right here. Down in this direction, it has got to get past this primary O-ring and then from there it can go to the secondary O-ring and escape out or it can go down the head of the bolt.

So it is that whole sealing system we are dealing with.

Senator KERRY. But the sealing is supposed to come through the threading itself, is it not?

Mr. THOMPSON. No, it is not threaded in here. It is threaded in this part. It is not threaded in this position right here.

Senator RIEGLE. If I may. This is confusing and it is important to raise, and I have spent some time on it and I think I understand it. But let me try it and see if I can make it understandable, because I want to make sure we have it right and we all see it the same way.

What they should have done was only thread the bolt part of the way up and the upper part of the bolt should not have been threaded, and then they could fit it in there much tighter and seal it much better. They did not know that and they inadvertently had threaded these bolts all the way to the end.

But we have been flying it that way for a very long period of time without the Stat-O-Seal, and no problems had arisen. But now you are sort of stuck because you have got the bolts already in place on the flight. They have got the threading all the way up to the end.

So you have come up with a means to seal the end of that bolt, to in a sense compensate for the fact that you have threading on the end of it where you do not want it. Now, I would like to sort of take John's question one more step, and that is, if that bolt did not work, if somehow that gas got in that threading what is the sequence of events that would follow?

What are the dangers here that we need to think about if it did not work properly?

Mr. THOMPSON. First of all, to ever get to this bolt and that metal to metal seal, which I will describe in a moment, it has got to get past the RTV, which it has never done to date. It has got to get past the primary O-ring. That has never been challenged because the RTV has always provided the seal.

And then yes, it can come out that bolt thread. Because of the benign environment, and we are running some tests on this, if all that occurred I do not think you would see any consequence at all.

But in dispositioning this problem, we are trying to make sure that we have got a good seal at that bolt. That is the way we started and we are going to end up relying upon a metal to metal seal. And I will describe that in a moment.

This is the bolt in question. The threading here does not go all the way to the head. It allows a shoulder, so I can show you how it is supposed to be.

And by the way, on the engineering drawing the minimum thread length was called out. It did not specify a maximum, and so the guy that makes the bolt threaded it all the way to the head.

This happens to be a bolt from the igniter which is similar. But again, the bolt in question here goes all the way to the end. There is a washer that goes on there first, and then this Stat-O-Seal, and the Stat-O-Seal I will show you in a moment, just has essentially a rubber O-ring on the inside.

So when we preload this bolt, then it squishes the rubber O-ring inside, and then that switches off against the inside diameter of the bolt and provides a seal so the hot gases cannot come up the shank.

Now, you can envision this. If the thread goes all the way to the end, you've got that rubber seal on the inside, but you've still got the path for the hot gas to get around and under the rubber. It does not go in and fill up all those grooves.

Let me just make a comment about how we got to this silly position. This washer was installed backward. The quality assurance people did check it and they found it. It was squawked. They wrote a discrepancy report. The combined engineering, manufacturing, and quality team then sat and tried to figure out, why did this washer get installed backward.

The instructions were poorly written. Let me get to the bottom line of that. It references a beveled surface on here. If you look carefully at the washer, on one side there's a beveled surface on the inside diameter and on the other side there's a beveled surface on the outside diameter. And so it is a little unclear to the guy that is installing it.

But you do not have to have this part in your hand more than about two minutes to see that, with the threads going all the way to the head, that it is going to totally negate the functioning of the Stat-O-Seal. So that is when it was caught.

We had already assembled the flight motors, which by the way are within about a week of shipping to the Cape. That in itself is no cause to leave it alone. We want to make sure that we have still got a good seal there.

We preload this bolt in with a minimum of 40,000 pounds per square inch, a maximum of 63,000 pounds per square inch. So we have got an excellent metal to metal seal here.

We conducted some tests where we put a lateral load on this bolt and displace it in sheer 23 thousandths, to make sure that we have still got a leak-tight joint. We have done that on a number of units. It retains the internal pressure and does not leak.

And so we are totally satisfied, I am totally satisfied that the configuration we have got today, even with this silly mistake in there, does not give us any risk in flight.

Senator RIEGLE. Now, the intention, as I understand it, is to use the existing bolts, which are not the way you would like them to be on the next flight, but then you plan to take those out, and you are going to have new ones in there after that. Is that right?

Mr. THOMPSON. Yes, with the caveat that this has not been reviewed yet with Dr. Fletcher.

So my own recommendation to him will be let us leave it alone. We know what we have. It has been leak tested. I have no concern on the integrity of this whole sealing system, and a change is not for free.

To take it down, you run the risk of something else, and I would do that in a minute, like we did in the DM-9 boot ring where we stopped and took the damn thing apart. I am, however, totally convinced that what we have is in good shape, but we still have to go through this with Dr. Fletcher.

Yes, I would get back to the right configuration because, again, it is crazy to be in this position. You totally negate the functioning of that Stat-O-Seal. We put quite a load on this thing. It creates about 75,000 pounds per square inch stress at that metal-to-metal interface. In normal design practice, 18,000 stress at a metal-to-metal interface is sufficient.

Senator RIEGLE. Now, how many of those bolts are there total?

Mr. THOMPSON. 72, and we have on both flight motors now a leaktight situation with this discrepancy. Frankly, what is giving us the leaktight situation is the fact that we have such a good preload on that metal-to-metal interface. We have a metal-to-metal seal as opposed to a metal-to-rubber seal. That was the design intent.

Senator RIEGLE. Now, for the record, and I want to be clear on this, despite the fact that you are convinced they are going to work, if they did not work what is the next step down the line? What does that then cause to happen, or what does that then jeopardize?

Mr. THOMPSON. You mean if this were to leak in flight?

Senator RIEGLE. Yes.

Mr. THOMPSON. There would be nothing in flight if this were to leak.

Senator RIEGLE. What about in terms of——

Mr. THOMPSON. Just a minute—assuming that we repeat our flight experience and we never get anything behind that RTV and to that primary "O" ring. The environment is very benign. We could leak at that bolt all day long and, until we get hot gas down to that bolt, we do not have a problem. That is in there as a redundant seal.

Again, because we are talking about relatively cool gas, and I hate to say 2,500 degrees Fahrenheit is cool but compared to our other joints it is because of the relatively cool gas, even with a small leak past there, I do not anticipate a problem. I am running some tests offline on this now.

I would change it out. I would change it out if we could not demonstrate that we have a leaktight bolt on the flight order. We have done that, however, and I would leave it alone.

Senator RIEGLE. Any other questions on that?

If not, I would like to then ask you are there any other items in this category?

Mr. THOMPSON. I would like to cover one other one, just a point on this. Let me reference a call that I got from Rick last week expressing his concern, and I will let him state it.

It is not of the configuration that we ended up with, because I think they have reviewed it and we have reviewed it, and we believe we have a good configuration, but the concern was more like how did we get there. With all the eyes we have looking at this thing, how did we let this thing get through?

Looking back on it, and I have talked to our engineering people, we just have to spend more time with the hardware in your hand and not just looking at it all the time on viewgraphs. We have done that in spades in all these joints.

This bolt change, this Stat-O-Seal change, was a fairly straightforward thing. We just did not get the right engineering eyes to put it in their hand and hold it.

The CHAIRMAN. You say you have done that on all these joints. Now, do not misunderstand. If I was put in charge of NASA in the next 10 minutes, you are the first fellow I would hire, because there is no doubt about your engineering abilities. You are on trial, and you are going to have to have the best kind of rocket motor and shuttle booster and everything else possible.

When you say the joints, now how do we check and check and doublecheck and doublecheck and then deliver rocket motors down there to Florida with flawed bolts, I think it is, in the boosters? That was not caught up there in Utah at Morton-Thiokol.

I am trying to find a good inspector general to get quality, because obviously, with all of this technicality, you know what you are doing, and this is fine. What about the regular manufacturer and quality control and the management there at Morton-Thiokol? That is what I am trying to find out.

How do we also deliver rocket engines right now and not find out that the welds are flawed until we get them all the way down to Florida?

Mr. THOMPSON. The bolt that I discussed is a Morton-Thiokol issue. The so-called fishmouth seal in the turbo pump is with Rocketdyne or Rockwell, and I will talk about that in a moment.

The welds on the aft skirt that we have gone in now with extra NDE is a part that happens to be made by McDonnell-Douglas. We have multiple——

The CHAIRMAN. Who is in charge of the welds which I am talking about that you were testifying to?

Arnie Aldrich, you know. You said the welds were defective, and you found it out when you got down to Florida.

Mr. ALDRICH. The welds were defective. The one that was found was in a teardown of a motor back at Rocketdyne, and Rocketdyne is responsible for the part that is in the high pressure fuel pump that had the defect.

The CHAIRMAN. Do we have quality control at Rocketdyne? That is what I am trying to get at.

We know now that we are not going to have the same mistake occur, but it is just like one of these modern automobiles. They have a computer to tell you how fast you're going and how much gas you're using

and what the market closed at in Tokyo and everything else on it. Then the dashboard and the wheel comes off. That is what I am worried about.

Here, you have ordinary welds in a rocket motor that are flawed and delivered on the job.

Mr. THOMPSON. Senator, we are continually concerned and looking at that. The part in question was found in a teardown in a normal cutup of parts to make sure that we have good integrity after that part has seen some service.

It had seen the equivalent in ground tests of over 15 missions. It is a static part that is bolted to the first stage nozzle of the high pressure turbo pump. It had gone through X-ray.

It had gone through a dye penetrant, which is an ink that we put down on the weld surface. We etch it; we rough it up with a chemical first to try to allow that dye penetrant to penetrate that discrepant weld. The weld was so tight that these two methods of NDE, the X-ray and the dye penetrant, just did not pick it up. That is why we go in and section the part.

We are now obviously reviewing all of that, and knowing that there is a problem in the dye penetrant, yes, a separate set of eyes can go in and find it.

I am very concerned about that. It is a constant fight that we are in to make sure that the Non-Destructive Evaluation (NDE) we have in the program is satisfactory.

A bad part can slip through X-ray, even with the best of eyes. Now, that is of no comfort. That is why we back it up with the dye penetrant. The dye penetrant did not catch it at this point. That is why we back that up, but we went in and sectioned it. We finally did catch it. There is plenty of margin in that part, but we are going to change it out.

It has seen the equivalent of 15 missions. There was no evidence of any high cycle fatigue, at most about four mils, four-thousandths. Even with the lack of penetration, we were in good shape there.

Let me just mention another one, because I introduced it a moment ago. This is on the aft skirt of the motor. We have been X-raying that part all along. The weld is about 1.5 inches thick. We have been X-raying it. As a part of this overall reassessment, we are now going in and using ultrasonics in the high stress portions of that weld.

The ultrasonics gave an indication of a lack of fusion. We went in then and re-X-rayed at different angles and, yes, verified that we have a flaw in one of the aft skirts on the first flight motors. They were in a very low stress field. The length of that lack of fusion was about three-quarters of an inch. It was located about a quarter of an inch below the surface of the weld, and it was about three-eighths of an inch deep.

Our analysis in that low stress field, knowing that the flaw was there with a lack of fusion, to give you a feel for the margin, that flaw could be three and three-quarter inches long and all the way through that 1.5 inch weld, and it would have to get that big before we would be concerned about it.

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I think it is more an indication in this whole review of going back and our engineering people questioning, particularly in the high stress field, that X-ray may not be good enough. Something can slip through. Let us go in and use ultrasonics. We did. That is how we found this.

Every analysis indicates that we are okay. So it is more and more——

Senator RIEGLE. I think that is important testimony that you have just given us. Now, are you saying that the weld problem, then, is as modest as you have just described? Where we did find with these unusual additional testing procedures, was that one area, or were there a series of areas where there were these empty places where there should have been welding material and was not?

Mr. THOMPSON. On the aft skirt, there was one area of any significance. We have looked at that in this position and can use it as is. We have plenty of margin area and, frankly, to go in and mess around with it would chase you into some other problem. So we have no concern on that.

On the The fishmouth seal, the problem there is what can you say positive about the parts in the flight article, because you cannot inspect them now. They are buried. So we are going to take the pumps out and change the part. We have gone through a special inspection. Knowing what to look for, we can find it every time, and we will be replacing those parts.

The CHAIRMAN. Is it not smarter to put that inspection back up at Rockwell before it is even delivered?

Mr. THOMPSON. That is what we are doing now. This X-ray and dye penetrant was done at a vendor. They are a qualified vendor. Rocketdyne has relooked at those X-rays, and they cannot see it, but we are bringing it inhouse where they are more attuned to doing this dye penetrant inspection.

On critical parts like that, we will bring them inhouse. We do not want to lose anything upstream. So that is where we are on that.

Senator RIEGLE. Could you just tell us for the record, and perhaps Mr Aldrich might be able to as well, how many individuals actually work on some part, some aspect of what finally makes up the package, the Shuttle, the rockets and everything that goes up? How many thousands of people or even tens of thousands of people?

Somebody obviously did that welding job, but I think we lose sight of the fact of how incredibly complex this whole system is and that we literally have thousands upon thousands upon thousands of people working all over this country doing parts of what then all gets fitted together to make this thing able to fly.

Can you give us round numbers?

Mr. ALDRICH. Mr. Chairman, I cannot give you a good round number, but I am certain it would be in the hundreds of thousands, at least 100,000 and probably more.

Senator RIEGLE. At least 100,000 and probably more?

I agree with Chairman Hollings. I like the idea of pushing this quality control right back to the source, so that even with our follow-up testing at NASA, we should not have that many mistakes to catch at the later stop down the line.

When we imagine the complexity of even trying to take on that kind of a task where you have all these different vendors——

Mr. ALDRICH. Mr. Chairman, could I expand a little further on what JR said about these kind of difficulties?

One of the major aspects of our recovery is to increase our technical penetration and communications within the program between the technical elements and the management. We have increased greatly the amount of detail and attention we are paying in all of these areas.

The welds in the aft skirt were found because we had a critical design review with engineers on the program determining that a new, better inspection could be made and we should do it. So we did, and we found something which we could not find before.

The problem with the fishmouth seal weld was found partly because we have increased the amount of testing we are doing in the main engine, the ground testing.

We had further experience and knowledge, and as we complete a certain series of tests we do teardowns and destructive testing to be certain we know how our parts and how our designs perform.

We find these kinds of things because we are intentionally looking for them. We discuss them, we review them at all levels, and we have increased the amount of attention to this process throughout the Shuttle system. I think as we go forward, it will need to more things we find, that we want to find, and that we look for.

This is very complicated technology, very highly stressed and highly technical parts, and we need an ever-ongoing program of attention to these things to give us the kind of flight hardware that we actually want to fly when we get to the flight.

So what we are finding here, I think, is a direct result of what we sought out to put in place as a system and the kind of things we intentionally try to look for and find at the right part of the program and not later when it could be a flight problem.

Senator RIEGLE. Now, I want to finish the list of any other major problems or difficulties that you have that you are working on or that you see.

Are there others that need to be mentioned here today?

Mr. THOMPSON. This is not a problem but it got a lot of hype over the week, and I would like to describe it to you. This is in the aft end of that exit cone on the tail end of the nozzle, the last 10 feet.

I have two samples here. What you see here is a part that we have cut out of what we call our ETM motor. We tested them back in the spring/early summer. It was an old 51-L motor, but we at that time had started incorporating some of our heater blankets that we were going to use. So it was a way to get some early data before we incorporated our redesign.

We used a nozzle, an exit cone that was 31 months old. It had been in the system 31 months, and back during the processing of that we lost vacuum. This undergoes a vacuum cure.

What we were trying to do was make sure that we could get all of the volatiles out between this carbon cloth with resonance in there. We had lost the vacuum here. During that process, we dispositioned it for ground test only, put it aside, and we tested it on the ETM motor.

What you see is a lifting of these plies, and I will pass this around. You see a lifting of these plies on that part. We were quite confident that we understood that this was associated with that loss of vacuum during the manufacturing process.

This happens to be, for reference, the same configuration that was tested on DM-8, the single crack that you can see there. You can see there is no lifting of plies. The single crack you see there occurs during the post-test cooldown. You can pull that apart and look at the surfaces and see no erosion there.

In the meantime, we have gone back and tightened up our controls in manufacturing, which was part of the team that Morton-Thiokol set aside. They had asked us to go through a number of things and tighten up these processes with the Thiokol or the NASA engineers. We all agreed those were the kinds of things we ought to do.

The team that was reported over this weekend is issuing their final report. They wanted to take a much bolder step in terms of changing the ply angles. We do not want to do that at this time. We see no need for it. We are conducting, in parallel, building up two nozzles with that change in wrap, but before we incorporate that into the flight design we want to make sure that we are not backing into a new problem like I talked about on DM-9.

So, yes, this got a lot of attention over the weekend. It is not a problem. We have thoroughly looked at it during the summer. It is one of a number of problems that we deal with daily.

I am very confident in the margin that we have on our aft decks and cone, and I only bring it to your attention because you recently read about it.

Senator BENTSEN. Mr. Chairman?

Senator RIEGLE. Yes, Senator Bentsen.

Senator BENTSEN. As you well pointed out, this is an enormously complex machine that they are putting up there, and I am sure that we have never had as extensive or intensive a look as what is taking place.

I am thinking of Mr. Thompson's responsibility and those in authority. They are never going to get a perfect machine up there. There are always going to be some marginal things in judgment.

I was listening to you discuss the depth of that weld, and I congratulate you on your courage and your judgment, because we are never going to be able to get up there with a machine that is totally perfect.

All that gets down to the fact that there is still going to be risk in whatever you do in this, because it is a dangerous and a tough assignment.

Senator RIEGLE. Are there other specific items that you feel the need to raise with us right now?

Mr. THOMPSON. No. I think I would just like to closeout this part of my testimony by telling you again as I did a year ago, one thing which we are really doing different in the program now is extensive testing.

Just this last year on the Shuttle main engine, we conducted over 10 hours of testing, which is the equivalent on a single engine of about 80 missions. A large number of these tests were at the limit where we are pushing that engine right to the point of breaking. We are trying to make sure that we understand where the soft spots are. We want to do that on the ground so we can fly right down the middle.

That is more testing in the last 12 months than we have conducted at any point in the Space Shuttle main engine program, even before we flew the first Shuttle launch, and we are also doing that in the solid rocket motor program.

So, again, that is the proof of the pudding, all this engineering. You know, you want to give it your best shot, but it has got to be able to go out to the test stand and demonstrate that we have the adequate margins.

Senator RIEGLE. Let me ask of Mr. Aldrich and Captain Hauck, starting with you, Mr. Aldrich, are there any other items, mechanical or otherwise, in the system at NASA as it relates to getting the Shuttle flying safely again that are problem areas at this point that you should illuminate and bring us up to date on?

Mr. ALDRICH. There are two problem areas with the Orbiter vehicle which we have been discussing for some time and that are under test. Until those tests are complete, which will be in about a month from now, they could be considered problem areas, although we have not had a recent anomalous condition of any kind to describe.

One of those is the 17-inch disconnect isolation valve which opens to allow the flow of both liquid oxygen and a similar valve for liquid hydrogen from the external tank into the Orbiter.

The most supported and desired change from the technical community to the Orbiter vehicle after the Challenger accident was to change this valve, which previously had been held open by spring tension and fluid dynamics, to provide a more positive latch to hold that valve open during the ascent phase.

So that any kind of anomalous flow condition, which we had never experienced but which you could conceptualize, would have a lesser threat to causing that valve to close and leading to a critical condition. That has been a major redesign and a major test program for this valve.

In defining and testing the latch, we recently ran some off-nominal testing conditions of that latch system, and it was found that a tolerance buildup on some of the units could cause rubbing between the previous valve itself and the new latch mechanism in the normal flight configuration for launch.

Rubbing the metal parts in an oxygen system is something that we try very, very hard to avoid in our designs. We have analyzed that, and we have incorporated a small stop mechanism external to the 17-inch disconnect which is a design change that limits the amount of travel on the latch. It allows it to be exactly in the right place and precludes this from happening.

That change was found right at the end of the design cycle in some off-nominal testing. However, it is a recent change in a critical area of one of the redesigns for first flight. We think now the design is complete. It has passed most of its certification testing.

It is right now, however, in the most stressful part of that certification testing; that is, certification tests with real liquid oxygen flow which are being conducted during the latter part of February and early March in our facility at Martin in Denver.

With the completion of those tests, we believe we will demonstrate all aspects of this part, including the correction of the recent rubbing condition that was found by analysis.

A second item in the Orbiter vehicle also related to main propulsion relates to a series of oxygen valves which flow pressure from the main engine back to the top of the oxygen tank to keep the tank pressurized as the oxygen leaves the big tank.

It cannot leave a vacuum behind it. It has to be backflowed. These are called gaseous oxygen flow control valves, and we also moved out with a design for those as a result of the review following the Challenger accident.

This redesign was also for the possibility of metal contact and potential ignition in a highly-stressed oxygen environment, and our new design incorporates both new materials and more benefitting flow path.

That design change has been made. It has been installed in the Discovery vehicle. It is also in its final tests for certification for flight. These final tests involve flowing oxygen through this valve at our test facility at White Sands and introducing metallic particles into the flow so that you have every opportunity to cause a metallic contact and lead to ignition. We are certifying that we do not have that potential in the new flow design, in the new material design.

I think these two are important changes in the Orbiter vehicle, but they are going very well, and we are near the end of all of the testing required to feel totally confident with them.

Senator RIEGLE. Now, again, thinking in terms of if the schedule holds together and being prepared to launch in roughly five and a half months here, are there any other problems that you see, whether they be engineering/ mechanical type problems or a system problem or any other difficulty that is out there that is a cause for concern that has to be dealt with and resolved prior to the time that we launch again that we now see?

Mr. ALDRICH. We have been testing a technique to extract the flight crew from the new pyrotechnic hatch that we have added, which are both elements of the escape system we have added to permit the crew with the capability to exit the vehicle while it is in controlled gliding flight to avoid a landing that is not at an optimum condition with an airfield.

We have implemented and tested and have full confidence in the pyrotechnic hatch and in the crew support system and the systems that they carry when they go out; however, two systems for a system crew exist from the vehicle in the windstream and avoiding recontact with the vehicle once they exist are still under test.

One of these uses a rocket extracting system. It is a rack of enough rockets for a total crew complement. Normally there are eight rockets in that complement, and it sequentially would allow each of the crewmen to use a rocket to pull themselves through the open hatch and assure clearance of the wing of the vehicle.

These have been certified and tested and can be ready for first flight. They involve carrying a system of high pyrotechnic energies, part of the Orbiter system for all flights. The likelihood of the need for this system is very low.

So as an alternative, we have been testing an aerodynamic escape mechanism which is a pole which is extended.

Senator RIEGLE. A pole?

Mr. ALDRICH. P-o-l-e, which is extended through the hatch after it is pyrotechnically jettisoned. It will allow the crew to hook onto the pole and slide to a point where they are clear of the vehicle before coming off the end and proceed with the crew escape sequence.

The pole system has been tested in wind tunnels, but we are still gathering data to be sure that it provides the kind of margin that we want for selecting it as the alternative to the tractor rocket system.

Also during the latter part of February and early March, we are doing live flight tests from an aircraft of this pole system to gain real data on the margins of separation and the crew procedures involved.

Both of those can be installed in Discovery. The provisions to mount either the tractor rockets or the pole system have been made. The pyrotechnic hatch is in place, and we will be selecting, we believe, one of these to fly on STS-26 as the preferred system.

Senator RIEGLE. So you have two options which you are developing, and you will make the decision later as to which you select to use in the next flight?

Mr. ALDRICH. Yes.

Senator RIEGLE. Any other problems. I want to get back to that one for a minute with Captain Hauck, but are there any other issues we need to know about?

Mr. ALDRICH. We have made a number of changes to the Orbiter landing system, the brakes and the hydraulics that power the brakes and the tires and the landing aids on the ground fields That is a long program and a complicated problem to solve for all conditions, so it extends well beyond first flight.

However, a number of important changes will be flown on the first flight, and we want to get test experience with them. For that reason, for the first several years of return to flight, we plan to land on the lakebed at Edwards in California, where we believe we have a very adequate landing performance margin.

We will be evaluating the changes we are making now. Also, downstream we will have some new, totally redesigned carbon-carbon brakes which will be a new element of the system, and we will test them also there.

So that is sort of an area of major redesign, but it is one that leads up to some careful decision for first flight and then concluding downstream in our flight program.

Senator RIEGLE. Does that cover the entire list? Is there anything else on the radar screen here that you see as a problem which you are working on that we need to know about?

Mr. ALDRICH. I tried to mention all the things we know about.

We talked about the fishmouth seal in the main engine.

We also have had concerns during the redesign period about high pressure turbo pump blades. We have done a detailed test program and come up with a new configuration for some of the blades in the high pressure fuel turbo pump.

Also, for the bearings we have come up with some limited life restriction on those bearings. That is also a test program that is closing out this spring and from which we do not expect additional surprises.

The main engine, as we talked about earlier, is very high technology, and there have been a number of areas that we have looked at carefully. So there are some ongoing technical answers that will round out our readiness for flight in that area.

With that summary, I believe I have mentioned those areas that concern me most. Of course, the biggest program to get through, I think, is competing the solid rocket motor test series. We talked about three more major firings before we are ready to proceed on to flight.

Senator RIEGLE. Now, I want to talk about the escape system, and then we will finish here shortly because we want to go to our other witnesses.

In the area of getting the personnel that you need, are you having any problems in that area? Are you able to attract and hold the talent you need coming down through this period of getting ready to go back into manned flight? Does that look pretty good?

Mr. ALDRICH. Well, I probably should start that, and then maybe JR will comment about his center.

In returning to first flight, I believe we have strong and adequate manpower leading to first flight, and we have projections as we build our flight manifest and flight rate upward from the first flight to projected final rate of 14 flights a year by 1994.

We have projected manpower increases to strengthen and expand the teams required to do the additional work for multiple flights as we go on through the end of this year and on into next year.

We had plans to augment our contractor work forces that do their processing at Kennedy and at Johnson, and I believe we are well supported in that area.

We recently added a new safety and reliability contract support here in Washington and also are adding quality and reliability support at the operations locations and at the test locations around the program. I believe that is going well.

Recently, there have been discussions of the Civil Service staff, and we also need some increases in that area. That is in detailed assessment and work by NASA now.

There are several options for reallocating within our current strength and also for perhaps augmenting certain critical areas in the downstream time frame. So I think we know what we need.

We feel we have the right staff and support for first flight, and we still have some additional augmentation that we are working on leading to the building of the manifest on the flight rate downstream.

Senator RIEGLE. Now, I want to nail this down very tightly because I do not want to have any unpleasant surprises later in terms of getting ready for this flight.

It is now five and a half months away with all the pressure that everyone feels buildsup to do it and do it right.

Your testimony today is that you have all the talent you need to do that job; that you are not shorthanded; that you are not in need of talents that you do not have or cannot get. Is that your testimony?

Mr. ALDRICH. Yes.

Senator RIEGLE. Now, in terms of the financial pressure within the system, are you also finding that you are getting the okays for the resources that you need and the commitments that need to be made to do the job? Are you feeling any financial pinch that is impeding your ability to do this job and do it right?

Mr. ALDRICH. We have a tight budget in the Shuttle as we do in all of NASA, and I feel the Shuttle has been very well supported and that we have a very solid shot at being in good total shape with our budget. I feel no extensive pressure at all at this time.

Senator RIEGLE. Mr. Thompson, is that true for you as well?

Mr. THOMPSON. Yes. I would echo what Arnie said. Let me take it in two parts.

I think we can get the very best young people today in NASA. The money is not that good, but the challenge is there.

We do need the spaces. Just at the Marshall Space Flight Center since the Challenger accident, we have added about 180 Civil Service positions. That is out of a total work force of about 3,400.

Right now, however, we are in the middle of a hiring freeze because of normal attrition. From that increase of 180, we have backed off now. We are about plus 80, so we have lost about 100. I think we have to come out of that.

Your new hires today are not going to help us for the first flight. I am more concerned over the long haul, and I think that is true at all centers.

The same for the money. As Arnie has indicated, it is tight, but we are cutting no corners on the first flight.

To me, the real trick is to keep our attention, our dedication and our commitment over the next decade, and unless we have the people and the resources to do that, if we are not careful we are going to be right back in the soup.

Senator RIEGLE. I think that is a very important point to make and is worth making. In terms of the focus today, however, I want to make sure that everything you feel you need you have, looking ahead to August 4. If you do not have it, now is the time to say so.

Mr. THOMPSON. We have it.

Senator RIEGLE. Okay.

Now, Commander Hauck, with respect to the safety system and the ability of the astronauts to get out in an emergency, I would like to hear your response to what Mr. Aldrich said about these two options that we are still evaluating and any of the thoughts you have either on those new safety options in terms of being able to try to get out or any other issues that are there that the astronaut foresees and feels needs to be raised.

Captain HAUCK. Thank you for the opportunity.

Arnie gave a good summary of the safety systems or extraction systems that we are working at and hope to have on the Shuttle prior to my flight.

I need to highlight once more that that is a system that would help us escape only in a very specific subset of emergencies. It would not help us in a Challenger-type accident. It is not designed to help us in that regard, although the explosive hatch could provide some assistance in an accident like that, in that we can get rid of that hatch immediately.

The two systems, the pole and the rocket, both provide the capability for us to get away from the wing or the pods on the tail of the aircraft should we have to jump outside.

If both of those test out as adequate to do the job, I think it would be common sense that we would prefer to have the system that is the simplest and that involves the least amount of potential hazard.

We have said from the very beginning that we do not want to incorporate an ejection or an extraction system or a bailout system if it complicates the normal way of doing business. That is not a good trade because, as Arnie said, the likelihood of having to use this is not very great.

So the bottom line is that if the tests that are coming up in the next few weeks show that the pole is an adequate way of getting out of the vehicle under those circumstances, we would probably vote for the pole because it does not involve having explosives added to the cockpit.

Let me say, though, that I have reviewed all of the designs and the implementation of the rocket as an extraction means, and I am confident that we have the right number of inhibits in safety provisions to not make the rockets themselves a concern.

Senator RIEGLE. Are there any other problems right now that the astronaut corp and that you particularly or all of you as a group are concerned about and that need to be put on the table?

Captain HAUCK. No. Arnie and JR have detailed, I think, very well.

Admiral Truly had made it clear from the beginning when I was named Commander of this flight that I should feel welcome at any venue, any discussion, any issue that goes on in the Shuttle program.

I have attended every one of his management council meetings in the last year since I have been named Commander of the flight. I think those have been very good, indepth discussions. I have been impressed with, in some cases, the volatility of the discussions. You know you

have good communications, I think, when you have differences of opinion and people are not afraid to bring out their sides of the story, and I have seen that.

I am also very pleased that other members of the astronaut office—I have mentioned the folks that had worked on solid rocket boosters, but also astronauts from the office are assigned to those critical systems, main engine, safety, reliability, quality assurance, across the board.

When the modification kits were being developed and manifested out at Downey, we had a person from the astronaut office in residence there, as we always have. We had people at the Kennedy Space Center. So I think our insight into what is happening in NASA is very good.

We also made it a point after we were formed as a crew to go out to each of the manned spaceflight centers. JR asked us to come down to Marshall. We went down to Kennedy several times. We have been to Marshall several times. Of course, we are in residence at JSC with the intent to get face to face with as many people. Arnie mentioned over 100,000 people.

I think that even though you cannot have meaningful discussions with a large number of people, we got out and saw and interacted with, even if it was just in an auditorium or walking through the production room floor out at Downey, I would say more than 20,000 people in the last year.

I think that is a positive step. It is good for us to be able to express our confidence to the people that are doing the work and it is also good for them to be able to look us in the eye and recognize that we are the flesh and blood that are going up in the Shuttle. So I am pleased with that opportunity.

We have touched on the access that JR and General McCartney and Aaron Cohen have granted us in bringing to them any problems about which we are concerned, and I think JR summarized the bolt situation very well. I have nothing to add to that.

I have no other concerns that have not already been discussed that I do not think are getting appropriate attention. I think we are doing well in that regard.

I am glad to see that the risk aspects of spaceflight have been emphasized during the hearing.

I am also glad to hear that there is obviously recognition that this is a research and development program, and that because in the slice of time today we do not foresee any other problems, that is not to say we will not see some tomorrow that we will need to face up to. That potential always exists.

Senator RIEGLE. If I may ask, then, in summary, when you as Commander of this next flight and all that that means and with the five and a half months ahead of us now as we are coming down through that countdown cycle, is your testimony as well that you feel confident and comfortable about what you see happening; that you, speaking for the astronaut corps, feel that everything is being worked properly at this point and that you have no reservations or concerns at this point that you think need to be flagged here?

Captain HAUCK. That is my testimony, yes, sir.

Senator RIEGLE. Good.

Now, let me ask you finally, Mr. Aldrich, is it correct to say that when that launch comes on August 4 or whatever the final date is here, you will be the person that gives that final okay for launch?

Mr. ALDRICH. We have made a change in our organizational structure as part of the recommendations of the Rogers Commission and some of our other reviews on the Challenger.

There is an element of my program office which is resident in Florida which has the responsibility for conducting flight readiness reviews and processing assessments on a day-to-day basis apart from other aspects and activities of the Shuttle program.

My Operations Deputy is Bob Crippen. He is in Florida now and has been in place for about a year. He has a team there and also at each of the key NASA centers.

The way our structure for the next flight has been arranged, Bob will lead a team following the FRR which sits in the launch control center and draws on not only the technical expertise from the projects and from the centers but also from the primary contractors on the Shuttle system.

He will make the final assessment of launch readiness and readiness to go based on the mission rules that are used by the flight team in Houston and the launch commit and launch processing rules which are used by the Kennedy team in the launch control center in Florida.

Senator RIEGLE. So is that to say that Crippen will be the last man to sign off?

Mr. ALDRICH. Yes, that is our plan.

Senator RIEGLE. That is the current plan. He is not here and cannot say this for himself, but I would like you to say it for him if this is accurate.

Is it clearcut that the policy is however late in the game, the last minute, the last day, the last week, the last month, if there is any problem that arises, we are not going until that problem is fixed?

Is that absolutely clear policy in NASA from at the top at this point?

Mr. ALDRICH. That is absolutely clear to me, and I think Bob would be even more positive that that is his policy in the way he has set up his operation and plans his process.

Senator RIEGLE. That is what we want to hear. I know this committee and the Congress and, I think, the country feels that we want to get back into space but we do not want to go one minute before we really feel we are able to do it.

I hope that launch date pressures, no matter how many times we may have to adjust them, will never be a factor that causes us to override a material concern. It seems to me that your first obligation is to respond to those concerns, and when we have nailed those down, that is the time to go.

That is your testimony today?

Mr. ALDRICH. Yes, it is.

Senator RIEGLE. Thank you.

I thank all three of you. I think this has been a very constructive discussion.

I am anxious to get to our next witnesses, but we are all part of the same team. We are counting on you to get the job done. We think you will get the job done.

Thank you.

Let me now ask Dr. Stever and Mr. Parmet if they would come to the witness table, please.

Senator RIEGLE. Dr. Stever, you are accompanied by whom?

Dr. STEVER. Dr. Myron Uman, who is the Project Director for this Project at the NRC.

Senator RIEGLE. Very good.

Let me identify our two principal witnesses here. Dr. Stever is the Chairman of the National Research Council Panel for the Technical Evaluation of the Redesign of the Space Shuttle Solid Rocket Booster, and Mr. Parmet is the Deputy Chairman of the NASA Aerospace Safety Advisory Panel.

These gentlemen by themselves and with their colleagues represent a very important aspect of our assessment of what our problems are and how we solve them in returning to safe manned flight in our space program, and you have heard the testimony this morning. I am going to ask you, if you will—make your full statements a part of the record, and I would like you, to make whatever initial comments you think are appropriate, but then I would like you to go directly to the issues that you think are the most important; and what the problems are that we may be facing; how serious are they; and are they being resolved to your satisfaction. If there are red flags that you see, now is the time to make that clear in this setting.

So with that spirit, let me start with you, Dr. Stever.

STATEMENT OF DR. H. GUYFORD STEVER, CHAIRMAN, PANEL ON TECHNICAL EVALUATION OF THE REDESIGN OF THE SPACE SHUTTLE SOLID ROCKET BOOSTER, NATIONAL RESEARCH COUNCIL; ACCOMPANIED BY DR. MYRON F. UMAN, PROJECT DIRECTOR

Dr. STEVER. Thank you, Mr. Chairman. It is a pleasure to appear again before your committee.

I will go through my testimony and try to hit the high points that you have just talked about. You will recall our third report, previous testimony about NASA's objective in the redesign effort, to return a safer and more reliable shuttle to service at the earliest possible date, and we all agree that those have to be balanced one against the other.

We recognize the importance of this balance. NASA's approach has been to follow two functional paths concurrently, developing and testing the baseline design to qualify it while at the same time building the components of the boosters to be used in the first flight of the baseline design. I think this concurrent testing and construction should be noted.

It is not uncommon in major technological developments. It does entail risks to the program schedule such as by building hardware that may have to be modified later.

It can be effective, though, in reducing the total time to complete the project. That is why they chose it.

The results of the development of Motor 9 illustrates the down side of this concurrency strategy. That is, when a component of the baseline does not pass, then as in the DM-9 test, the baseline design of the nozzle outer boot ring, which had already been installed in the nozzles of the first flight set, the redesign team, finding that that did not perform satisfactorily, fortunately had a backup for it. The result was a delay, but that delay was less than if they had not had that backup.

By the way, the new problem of the bolts, the threaded bolts, is exactly the same kind, presents the same kind of difficulty, and a decision which has not yet been made, an analysis has to decide whether that is accepted as it is or brought back for change.

Now, the central feature of the certification program that remains to be done is a series of three full scale, full duration motor firings. This was in NASA's testimony. It should be noted very carefully.

Meanwhile, the rocket motor that is to be fired in the first firing is about to be shipped. The launch could occur within months after the satisfactory completion of the third of the four motor test firings, provided everything goes well. Many features are aimed at improving flight safety, and these design improvements resulted partly from the consideration of the possible causes of a failure of the case field joint during the Challenger test, and partly from the re-examination of known weaknesses in other components, particularly in the nozzle and case-to-nozzle joint, another feature that should be noted very carefully, because I will return to that later in this testimony.

Leaping ahead next to the design itself, the most important determinant of success, and I think Senator Hollings would be pleased to hear this, not only for the first flight but also in the long run, will be the assurance of quality in materials, manufacturing and assembly of the motor components. This is especially true for a solid rocket motor because the flight test article itself, or the flight article itself can never be tested.

You talked this morning about the liquid propellant rocket motor and the flaw in the welding that was found. That was found because a liquid propellant rocket motor which is to be used in flight can in fact be tested before, but the solid rocket motor can never be tested. And so the entire burden is thrown back to the assurance of the quality and the materials, how the thing is manufactured, the processes, how it is assembled, how it is handled, and so on.

One of the more challenging processes to control is this bonding of the insulation in the case-to-nozzle joint while avoiding the occurrence of the flaws caused by trapped gas bubbles, and so far no one has quite found a process which ensures that there are not going to be some trapped gas bubbles.

There are numerous other quality control issues which I will not take up here.

Now, the principal focus of the testing program between now and the return to flight is certification that the design meets the requirements for a flightworthy shuttle booster. Certification testing is accomplished in both short duration and full duration firings, and fortunately there will be more of both kinds.

The JES, the NJES, the TPTA for the short duration and the full duration firings which were mentioned in the NASA testimony are particularly important. They are supposed to be exact replicas, NASA's own rules, replicas of the flight design except that certain flaws will be introduced in QM-6 and PVM. The QM-6 flaws will be representative of damage that could be introduced during the manufacture or assembly but that could not be detected before flight, a very important set of tests.

In other words, the design must be tolerant of such damage.

The flaws in PVM are introduced for an entirely different reason, to certify the performance of the primary seals by assuring that gas pressure reaches the primary O-rings during the test. You have heard a lot of talk about damage to the primary O-ring in the earlier flights, in the 51-L, and in tests, but the fact is the redesign of the joints has some features which may prevent you from ever testing those dual, redundant, verifiable seal system because the hot gas during test may never get to the O-rings to test the system.

So some important new features, and particularly the new features of bonding the section, the insulation in the sections together, which is a new kind of design feature, that has proved so successful that you do not get to test your primary and secondary seal, a very important point. And in that finally, the PVM, there are going to be tests to get hot, high pressure gas, or hot gas to those seals.

If you had asked me, as you asked the earlier witnesses, to pick out the most important things that have to be done, I may, and my committee, I think we would have picked that first, the tests that are going to be in that last of the three motors.

Accomplishing the required testing before the scheduled date for the resumption of flight is certainly going to be a challenge. There is not any slack time left now. The proof of the worthiness of the design, however, is in this test program. It must be accomplished, and accomplished successfully.

If you were to ask me when I think the next shuttle launch will take place, I would answer simply, when the certification and the qualification testing program is completed, not the redesign, but testing, and the manufacture and assembling processes are in control, two things.

Senator RIEGLE. Now, I think that is very important testimony.

Are you saying between the lines of that testimony that to be able to get that done in five and a half months, August 4, is maybe unrealistic in your view?

Dr. STEVER. No, not yet, but I will say that success has to be found all along the way.

I think Commander Hauck mentioned the fact that this is an R&D program, and sometimes you do get unexpected results that have to be taken into account.

Senator RIEGLE. And so I think we then would draw the conclusion from what you are saying that if the facts as they develop tell us that we are not ready or that we need more time, that those dates would have to slip accordingly.

Dr. STEVER. Exactly.

I have one other important point, sir. NASA, in its contracts, as well as the NRC, have focused their attention almost exclusively to returning the shuttle to service for that first flight. Little consideration has been given to the SRM program beyond the first flight except for the manufacture of flight sets. In its third and fourth reports, our panel pointed out the importance of an ongoing program to improve the safety and reliability of the shuttle booster design even beyond the flight testing we are now getting or we will get.

While NASA strives to make the redesign as safe as practical within the constraints of time and budget, we ought not to accept the notion that the new designs are as safe as they might otherwise be. In fact, had they had this kind of program following the earlier ground tests, preflight ground tests and during those many successful flights, I do not think they would have the outer boot ring having the problem it had. They would have had to test those things, and they would have introduced it.

Senator RIEGLE. I have to agree with you, and I would say that the findings of the Rogers Commission were to the effect that we had problems, that the problems that doomed that flight were avoidable problems. They were problems that could have been found and could have been fixed. So I think your point is well taken.

Dr. STEVER. So I will just say that I think we have got to have a well staffed and funded program to do that.

Let me conclude my testimony by again expressing our appreciation for the willingness of the redesign team to discuss technical issues in detail with us. The team works hard and is dedicated to its objectives. We, on our panel, have been particularly pleased that the astronauts assigned to the redesign of the solid rocket motor have attended our panel meetings, and in fact, occasionally have engaged us in excellent interchange on technical matters.

I would be glad to answer any questions.

Senator RIEGLE. Well, I have a couple of questions now before we go to Mr. Parmet, and that is as we come down this countdown cycle here, and as we resolve these problems that remain, that have been identified today and any others that come up, if the National Research Council panel finds that it is not in agreement with what the decisions are that are being made operationally within NASA, what is the procedure that you follow to register the fact that you are in disagreement?

Dr. STEVER. First of all, we speak directly to Dr. Fletcher, and that is in our contract that we report to him, and a second very important feature of our study, and all the National Research Council studies, is that we write reports which cannot be suppressed by anyone. They are reviewed very well, and within NRC, but once they are written, they are published publicly. That is a fairly heavy torque that we have.

By the way, our relationships with Dr. Fletcher are excellent. He listens very carefully and has taken up our important recommendations very well. So I do not think we need that kind of torque, but in fact, you will hear publicly that if we disagree with something.

Senator RIEGLE. Your job is to be independent, is it not?

Dr. STEVER. Yes.

Senator RIEGLE. And I take it that that is fully your intention as the Chairman, and that your panel members feel exactly the same.

Dr. STEVER. Yes.

Senator RIEGLE. So if we come down to the launch date and problems are unresolved or should arise, you are going to make that known first internally, but failing all else, you will publicize those differences?

Dr. STEVER. Yes. However, do not think we are in that decision line that was described by NASA. This is going to be a NASA success. I am confident it will be a success. But we will make known everything, the status of the issues that have come up, and they will have to make the tough decision to launch.

Senator RIEGLE. Absolutely.

Now, I want to make it clear, too, that the subcommittee and full committee very much wants to have any information or observations of that kind that you have to make as we go down the line here. If there are any significant differences of opinion that are not resolved, we expect to be informed, and I gather you are prepared to give us the assurance that you will so inform us.

Dr. STEVER. We will.

Senator RIEGLE. Thank you.

[The following information was subsequently received for the record:]

Responses to Senator Riegle

Question #1: Dr. Stever, the NRC Panel in each of its reports has reiterated the fact that the "proof of the worthiness of the design is in the test program." Today, your statement has included another critical element -- "control of the manufacturing and assembly processes."

How would you rate the program's overall success in "controlling the manufacturing and assembly processes?"

What specific steps have NASA and their contractors taken to assure quality in materials, manufacturing, and assembly of the motor components?

What specific steps have they taken to define and maintain the essential controls on materials and processes?

Response: NASA and its contractors are paying a great deal of attention to the control of manufacturing processes and materials and have made significant improvements in a number of areas. Problem areas remain, however, and the need for careful controls on the manufacturing -- and assembly -- processes is a continuing one. That need will be as important for the 100th mission as it is for the next.

Examples of areas of where a considerable amount of work has been done are in the procurement of O-rings and the assembly of the case field joint at Kennedy Space Center, where environmental controls have been installed to minimize the introduction of contaminants during bonding operations. An example of an area where additional work is needed is the manufacture of insulation that forms the thermal barrier in the case field joint.

Question #2: Dr. Stever, in your statement you indicate that "while NASA strives to make the redesign as safe as practical within the constraints of time and budget, we ought not to accept the notion that the new designs are as safe as they might otherwise be."

In the opinion of the NRC Panel, what are some of the specific areas of design and manufacture that are acceptable for the return to flight but that require further testing and modification?

Response: The Panel is reviewing aspects of the design, manufacture, and assembly of the SRB to develop a list of areas that might be included in a program of continuing development and improvement after the return to flight. We are not ready to make formal recommendations on the details of a comprehensive program at this time, but in our most

recent report we did recommend a hydroproofing test of a case field joint that included 20 cycles of assembly, pressurization, disassembly, and measurement followed by a burst test. The test is needed to help determine the reuse potential of the new case design. Some other topics under consideration by the Panel include: machining and finishing of case hardware to assure an interference fit at the case field joint capture feature, improvement of bonding processes to reduce the occurrence of unbonds between the case and insulating liner, and alternative approaches to assembling the case-to-nozzle joint so as to avoid the occurrence of voids in the current polysulfide adhesive.

Question #3: Dr. Stever, there has been much discussion in the press concerning NASA's position on safety versus the pressure to launch.

In the eyes of the NRC Panel, has NASA maintained the proper balance between flight safety and the flight schedule?

What is NASA's philosophy towards space shuttle safety, and how does that compare with the Panel's philosophy?

Response: The Panel addressed this question in its most recent report, dated March 17, 1988, as follows:

"The objective of the redesign effort is to return a safer and more reliable Shuttle to service at the earliest possible date. Safety and reliability, however, are not absolutes. The desire to provide the safest and most reliable design can conflict with the desire to return to flight as soon as possible. NASA has to make judgments about whether additional improvements are worth the delays in the return to service that they imply. Flying the Shuttle or any other space transportation vehicle will always entail accepting some risks.

"Thus far, we find no evidence that the redesign team has taken or will be taking undue risks in favor of an earlier return to flight. However, in this as in other large aerospace systems, schedule and budgetary constraints have affected the program so that the risks associated with the first flight of the redesigned SRB, while acceptable, will be higher than if the program were not so constrained. It should not be necessary to continue to incur this additional level of risk throughout the service of the redesigned SRB, however, if there were a program of continuing development and product improvement beyond flight testing.

Question #4: Dr. Stever, you emphasize the point that the space shuttle is a research and development vehicle, not an operational vehicle.

Does this mean that the space shuttle should continue to be improved and upgraded after the next flight? What specific upgrades or improvement programs would you like to recommend to the Subcommittee?

Have any activities, tests, design modifications or improvements been deferred by NASA that are of concern to ASAP or the NRC?

Does your position change if an Advanced Solid Rocket Program is initiated in FY 1989?

Response: The Panel believes strongly that improvement of the SRB design, manufacturing, and assembly processes should be continued after the return to service. One reason is described in my response to question #3. Another is that the SRB can only be tested in the most realistic environments in flight, so the first few flights will provide additional data useful for defining risks.

As I indicated in my response to question #2, the Panel has under consideration its recommendations of areas where the design might be further improved.

The initiation of an advanced solid rocket motor (ASRM) program in FY 1989 would not change the Panel's position on the need for an appropriately staffed and funded program for improving the redesigned solid rocket motor (RSRM) after the return to flight. First, we cannot predict whether or when an ASRM would become a reality even if the program were to be initiated in FY 1989. Second, we cannot assume that improvements that have thus far been deferred or problem areas that might arise as a result of flight testing will be sufficiently unimportant that the National Space Transportation System can wait for the ASRM to make the necessary changes. Third, continuing improvements made on the RSRM will also be valuable for enhancing the effectiveness of the ASRM.

Question #5: Dr. Stever, the NRC Panel has been involved with oversight of the space shuttle solid rocket motor redesign activities since June, 1986.

Based on your respective organization's activities, are there any specific concerns that you still have, any deficiencies that need to be corrected on the solid rocket motor before the flight of Discovery? Or has NASA isolated the principal concerns?

Response: The redesign has been completed and the program is now in the process of verifying by test and analysis that the design meets its requirements. I believe that NASA and its contractors have identified the major deficiencies of the original design and incorporated improvements in the redesign to account for them. As I indicated earlier, however, operation of the RSRM will not be without risk.

Question #6: Dr. Stever, in the aftermath of a tragedy, there's always a tendency to redesign every nut and bolt.

Has NASA been able to balance the conflict between doing too much redesign work and doing too little? Has the focus of NASA's redesign activities been to gain additional margin, improve performance, or increase safety? When do you freeze redesign activities?

Response: The objective of the redesign program has been to improve the margin of safety. The program has not attempted to improve performance, deferring that objective to the substantial increases in performance envisioned for the ASRM. The redesign has increased the weight of the SRB and thus has actually had a small adverse effect on performance.

Question #7: The proposed SRM test program is a critical element in determining the flight status of the space shuttle.

Does the NRC Panel agree that the proposed SRM test program is the best means to verify the integrity of the actual SRM flight hardware?

Does NASA manifest the necessary a priori knowledge, and do their pre-test predictions compare favorably with the test results?

Should the SRM test program be maintained after STS-26? How many full-scale and sub-scale tests per year?

Is NASA properly equipped to conduct a thorough test program, or should these activities be contracted out?

Response: The Panel agrees that the best means for verifying the appropriateness of the new design is by subjecting it to a rigorous test program. Recognizing that there are practical limits to the amount of testing that can be accomplished within constraints of time and budget and noting that the next six flights are included in the certification program, the test program appears to us to be adequate.

As you may recall, in an earlier report we discussed the importance of making detailed predictions of the performance of articles before tests are conducted as means for increasing confidence in the design. The Morton Thiokol test engineers have been making pretest predictions which usually compare favorably with the results.

The need for a continuing program beyond STS-26 has been emphasized in response to earlier questions. How many tests should be planned and of what type remains to be determined. In our most recent report, we urged NASA to begin planning

for such a program now; that planning would include the definition of the types of number of tests that might be included.

Question #8: In the aftermath of the Challenger and Titan 34-D accidents, it became clear that better non-destructive evaluation (NDE) techniques were required.

NASA has installed a new X-Ray facility at the Morton Thiokol Plant and has initiated physical and ultrasonic testing of the solid rocket motors at the Kennedy Space Center.

The Air Force, however, also has installed a new X-Ray facility at the Cape.

How does the NRC Panel rate the new NASA non-destructive evaluation test program?

In the judgment of the NRC, should NASA have an X-Ray facility at the Kennedy Space Center to inspect motors after they have been stored and transported?

Has NASA significantly improved its NDE testing, including X-Ray, ultrasonic, and physical testing?

Response: NASA and Morton Thiokol have made considerable improvements in their capabilities for nondestructive evaluation of motor components by both more aggressive use of technologies previously employed and adoption of technologies to new uses. The need for appropriate inspection procedures after transportation to and storage at Kennedy Space Center (KSC) is clear, particularly in light of the potential importance of unbonds between the case and insulating liner and between the insulating inhibitor and propellant. While NASA has not installed an X-ray facility at KSC, it has introduced a new pneumatic tool for uncovering edge unbonds. Whether NASA's capabilities for inspecting motor segments at KSC is sufficient remains an open consideration for the Panel at this time.

Responses to Senator Pressler

Question #1: Dr. Stever, according to the February 14 Washington Post, an internal NASA report concludes that the carbon ablative material in the SRM aft exit cone poses a risk of "borderline performance" and recommends that changes should be made in this material before the next flight. This report reportedly goes on to say that in previous tests, the material has suffered defects serious enough that the "integrity of the entire exit cone comes into question."

Furthermore, I am aware of the June 22 report of your panel that expresses concern about lack of fundamental understanding of this carbon ablative material.

Were you aware of this internal NASA report on the carbon ablative material in the aft exit cone, and does your panel believe that this material represents a risk as serious as this internal NASA report has concluded?

Response: I was not aware of the report on February 16th. The report was prepared by a task force organized after the firing of the Engineering Test Motor in May, 1987. During that test, the aft exit cone demonstrated poor performance. The possibility of this performance was recognized at that time, however, because the part had been manufactured improperly. The part had been set aside for ground test use only.

The carbon cloth phenolic material used in the aft exit cone as an ablative is a complex material; its behavior is difficult to predict analytically. Thus, the proof of its performance is in the testing program. Unfortunately, subscale tests are usually inadequate for assessing the performance of full-scale parts because of the importance of the geometrical relationships of the cloth wrappings imbedded in the part to the configuration of its environment. We thus must rely on data from the few full-scale tests.

In the full-scale tests of the aft exit cone conducted to date in which the part has been manufactured according to specified processes, i.e., Development Motors #8 and #9, the part has performed satisfactorily.

The report recommends a number of options for improving the manufacturing processes, a number of which has been adopted by NASA. The aft exit cone will be subjected to three additional tests before the return to flight. Data from these tests will help to confirm the adequacy of the manufacturing process and quality control procedures.

Question 2: Dr. Stever, do you believe that the present carbon nozzle ablative is safe for the next Shuttle flight, or should changes be implemented before this flight?

What is the likely outcome should this carbon nozzle ablative fail in flight?

Response: The carbon cloth phenolic is used in a number of nozzle parts as an ablative material. That is, the material is consumed and its properties altered as it performs the function of protecting metal parts in the nozzle from the heat of the rocket gases. Whether the ablative parts should be flown will depend on the results of the test program and there are three additional tests of these materials scheduled to be performed before the return to flight.

The consequences of failure of a nozzle ablative part during flight are many, depending on the part and when in flight it fails. For example, the throat is a critical part and its failure could have catastrophic consequences. Since the Challenger accident, this part has been redesigned to improve its performance and increase the margin of safety. The outer boot ring, on the other hand, is a less critical part, providing thermal protection to assure that the flexible bearing can be reused. Analyses performed by NASA and its contractor suggest that if this part fails, it is most likely to fail late in or after motor operation with little, if any, consequence for safety.

Question 3: Dr. Stever, according to your panel's June 22 report, the current baseline design of the case-to-nozzle joint is likely to fail to meet the requirement of prohibiting the appearance of thermal distress when tested in the presence of a flaw extending directly through both the adhesive and wiper O-ring.

What has your panel observed in terms of NASA addressing adequately this urgent concern -- to what extent is your panel still concerned about the ability of the case-to-nozzle to meet this requirement?

Response: NASA is addressing this concern, which is aimed at understanding the performance of the sealing system under test circumstances in which the test hardware is deliberately modified from the flight design. A number of short-duration tests and one full-duration test will be performed with these modifications to provide the data from which to judge the effectiveness of the design. Our most recent report to NASA addressed the question of an appropriate criterion for judging the success of these tests.

Question 4: Dr. Stever, you are no doubt aware that NASA recently discovered that the bolts used to connect the SRM's fixed housing to the booster for STS-26 were not the bolts designed for this mission but, instead, were the bolts designed for the old SRM design.

Should NASA replace the bolts and accept another delay in the first launch, or is flying without this redundant "stat-o-seal" an acceptable risk?

Response: First, the bolts to which you refer are not the ones that connect the fixed housing to the booster (commonly called the case-to-nozzle joint) but the ones connecting the fixed housing to the flexible bearing assembly (commonly called internal nozzle joint #5).

Only NASA can judge whether the incremental risks are acceptable. Leak checks of the first flight boosters and laboratory simulations have been conducted to gain confidence in the acceptability of the bolts. The bolts were used in Development Motors #8 and #9 and will also be used in Qualification Motor #6.

It should be noted that the configuration of the joint seals does not differ significantly from the earlier design, in which a rubber O-ring, protected by an adhesive sealant, formed a primary seal and a metal-to-metal contact between the bolt head and housing formed a secondary seal. While the improperly used fully threaded bolt does not form a seal with the rubber part of the new stat-o-seal, it does form a seal at the metal-to-metal contacts between the bolt head, washer, and housing. The leak check port added in the redesign now provides the opportunity to verify the seals with a leak check after assembly, thus adding a measure of confidence.

Question 5: Dr. Stever, according to the June 22 report of your panel, NASA should implement inspection procedures other than visual inspection for motor segments removed from long-term storage before assembly. Furthermore, your panel recommends that NASA pursue more vigorously the installation of an environmental control system to protect case segments during assembly.

What has NASA done to address your panel's concerns about inspection procedures and environmental control of motor segments?

Response: An environmental control system has been installed in the Vehicle Assembly Building at Kennedy Space Center (KSC), substantially improving cleanliness during assembly operations. Environmental controls are always a concern in bonding operations, such as occurs in mating the case field joints at KSC. Other critical bonding operations take place at the Morton Thiokol Wasatch plant in Utah.

The adequacy of inspection procedures, particularly after long-term storage at KSC, is still under review.

Question #6: Dr. Stever, according to your testimony, NASA was fortunate to have an alternative design for the outer boot ring when the DM-9 version of this boot ring failed.

Do you believe that NASA has pursued adequately contingency plans for other SRM components and, if not, to what extent does this deficiency in contingency designs exist?

Response: Other than the outer boot ring, no major part has been carried this far into the test program with alternative designs. A number of alternatives were considered earlier in the design phase of the program but only a few were subjected to any tests. Now that one of the alternative designs for the outer boot ring has proven to be unsatisfactory, there are no alternatives available in the event of contingencies. The program therefore is at risk should any part of the design fail to meet the requirements as a consequence of the upcoming qualification tests.

Question #7: Dr. Stever, according to your testimony, next to the design itself, the most important determinant of success, not only for first flight but also in the long run, will be the assurance of quality in materials, manufacturing, and assembly of the motor components.

What has your panel observed in terms of NASA implementing and maintaining this quality assurance?

Do the recent discoveries of weld flaws in the main engines and SRM aft skirts indicate to you a serious deficiency in quality assurance?

Response: Since the beginning of the redesign program and continuing to today, NASA has made important progress in improving quality assurance and raising the importance of quality assurance in its priorities. A case in point is the O-rings, for which a number of significant improvements in controlling the manufacturing and testing processes have been implemented. Important problems remain, however.

The panel cannot comment on the weld flaws in the main engines, but it has reviewed data regarding the flaws recently discovered in a number of booster aft skirts. The latter defects were discovered as the result of the application of advanced technology for nondestructive evaluation. The importance of the defects depends on where in the part they occur. Their discovery is an indication that NASA has improved its capabilities for assessing quality, not that the agency's previous attention was necessarily insufficient. The technology now employed is superior to that used previously.

Senator RIEGLE. Mr. Parmet, you are the Deputy Chairman of the NASA Aerospace Safety Advisory Panel. You were formerly the Vice President of Engineering for TWA. You have a statement. We will make that part of the record.

In the same manner, I would like you, if you would, to go right to the points of greatest importance here today in the context of this hearing.

STATEMENT OF NORMAN R. PARMET, DEPUTY CHAIRMAN, AEROSPACE SAFETY ADVISORY PANEL, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. PARMET. Thank you, Mr. Chairman. I will try to do this to the best of my ability.

I would start by pointing out that we have one member on Dr. Stever's committee. We have several members on other NRC panel activities, so I am not going to repeat anything that Dr. Stever has said because we support his activity.

Last year when I appeared before a House committee, Bill Nelson's House subcommittee I had a big shiner, 12 stitches in my head over the right eye, and a broken nose, and he wanted to know what the heck happened, and I said, well, we did not have full agreement amongst our panel, and some of my friends wanted to know what I was going to do for an encore, and I decided that I would try to come clean today. And they told me that it was no improvement.

Well, we are currently completing our annual report, and we will present this to Dr. Fletcher on March 16, and on that same date, we will make available to you that official report.

In the interim, we have produced a brief in response to your question related to the first flight: Is NASA Ready to Go? And I should like just to make a few remarks related to that brief, and then try to answer any questions which you might have.

I would like to cover our general view on safety, then discuss briefly NASA management improvements as well as communication improvements, the risk assessment process, which I think is a very, very important aspect of this return to flight, some hardware changes which are pretty much like Arnie Aldrich had discussed, and then I would like to talk about national space policy.

First of all, I believe, and our panel concurs, that the current efforts of NASA will lead to shuttle operations that are safer than those prior to the Challenger accident. Nevertheless, we still regard the STS program as an inherently high risk venture. You may recall that

President Reagan, after the fourth shuttle flight, declared it an operational system. Well, that statement was incorrect then, it is incorrect now, and it is going to be incorrect for the foreseeable future.

The shuttle remains a development vehicle, although it can carry operational payloads. And I do not want there to be any confusion as to that aspect of it.

One of the major recommendations of the presidential commission was the establishment of a management structure to assure that the effort involved in bringing the shuttle back into operation was properly directed and that management was in a position to control and provide direction through an effective communications system. A reorganization has occurred. A line organization has been set up with all elements of the system reporting to headquarters, and that was a major step forward as far as we are concerned.

The STS program is now managed with a consistent set of directives and with a much improved communications system.

The assessment and management of risk remains a crucially important task for NASA management. Subsequent to the Challenger accident, NASA has conducted a complete review of its approach to risk assessment. This comprehensive review was one of the most extensive ever conducted for a large aerospace system. A complete review was made of all failure modes and effects analyses, and a critical items list was developed. Hazard analyses and then the waivers granted through what is called a retention rationale were looked at all over again This thorough effort should provide a safer operation.

However, we are concerned that this massive effort is not the most efficient way to proceed and believe that NASA must find a method for prioritizing this work so that it permits dealing with the most serious problems first and leaves the highly unlikely for later action.

NASA is still working hard on methods that will enable them to prioritize the work, although I just received this morning a copy of their new risk assessment, what they call an NMI, and it does cover prioritization. I had not had the opportunity to read it yet, but they are taking the proper steps.

Although the risk assessments have not revealed a large number of changes required to meet the design, operation or certification ground rules, there are several areas where the implementation of design changes critical for safe flight were long overdue. Of the thousands of items contained in the review, there are over about 250 that are considered mandatory for incorporation before the next flight, and NASA is handling those. Some of those, I will mention the solid rocket motor field joint and the solid motor aft segment case-to-nozzle joint, but I will not say any more about them—I think we have designed that several times today—the oxygen tank pressurization valve with the material change that was mentioned by Arnie Aldrich, the main engine high pressure turbine cracking problem, which is a durability problem and one in which NASA is working on, and they will probably limit time on the engines until they get that one thoroughly solved. The 17-inch liquid oxygen and hydrogen shutoff valves are items that we are watching very carefully, and we will pursue that right to the very end.

Speed controls on the solid rocket booster APU to prevent an overspeed condition is being worked on.

And then there are problems with structural load margins on the orbiter's wings and other structures, which NASA has analyzed and reanalyzed, and we have found that the structural margins in certain areas, for example, in the wing and wing-to-fuselage joint area are less than anticipated. As a result there are some structural modifications being made for the first flight. However, there has to be an overall look at this, and NASA is completing an analysis which they call ASKA-60 which look at all of the loads.

In the meanwhile, they have to fly in a more restricted range because of the lack of margin.

Senator RIEGLE. Now, when you say fly in a more restricted range, you mean with respect to the total weight of what is going up or in terms of the maneuvers and so forth that would be done?

Mr. PARMET. Well, I hate to use this term, but NASA uses it. It is called a squatchaloid, and it is——

Senator RIEGLE. Can you convert that to sort of plain English?

Mr. PARMET. I will try to.

There is a whole envelope within which the vehicle has to fly as it leaves the ground and goes into orbit. If the upper winds, for instance, are higher than normal, then maneuverability of the vehicle is limited, and perhaps in a worst possible case you would have to cancel the flight. Now, if you have structural margins that are sufficiently wide, the squatchaloid is wider. If you have concerns about how much margin you have, you narrow this down. So you have got to fly through a narrower hole is the best way for me to express that.

Senator RIEGLE. I see.

Mr. PARMET. So I have no concern about them exceeding these limits on the next flight, but I do think that in the long term it limits what the vehicle can do.

Senator RIEGLE. Now, this is a new one for me. I have not heard previously about the possibility of a structural problem in terms of wing loads, given the whole range of things that might happen. Not, as you say, looking specifically at the next launch, but over time.

Mr. PARMET. Well, in a sense, it is not something that will lead to failure of the flight, but it just says hey, you thought you had this much margin but you have got less margin. Therefore, you have got to be a lot more careful in how you plan this flight and make sure that you do not exceed certain limits.

So you limit what your capability is. If it were an airplane, like I am used to, if it were a 150,000 pound airplane and I found all my structural loads were at 150 percent, say, instead of 100, I might have to download that vehicle to 100,000 pounds to make it safe. But then it would not be economical, so I would not fly it. But it is that kind of thing.

I would like to also mention landing and deceleration modifications to the orbiter. Arnie mentioned brakes, and I coming from a commercial field feel that this one has dragged on too long. Development of

carbon-carbon brakes has been on our agenda for NASA to do for over four years, and in the commercial world you would have it done by now.

Part of the problem is economics, I think. You have a limited amount of funds, and you have to decide how to use those funds. I suspect that is what causes NASA to work at a different pace than we would commercially.

I would like to, before I conclude, add someadditional remarks. One, I feel that America needs a clearcut policy for civilian use of space, and I understand that such a policy has just been released on February 11, and it was handed to me a few hours before I walked into this meeting. The fact that there is a policy now is very important. I may not agree with it, we may or may not agree or even may agree with it, but it is there. It is a guideline for this country to follow, so we have consistency in the approach to what NASA should be doing in space.

Senator RIEGLE. Mr. Parmet, let me just say at that point—and I want you to elaborate—we clearly do need a policy. We have not had one, a clear cut policy, I think, for a long time, and many of us have pressed hard for that. It has been a subject of debate. It has been a subject of legislative initiative here, restructuring of the government, re-establishment of the National Space Council, putting the Vice President in charge to really give it a focus, so that while we have one and you were handed one on your way in the door today, it has been developed by an administration that is on its way out the door. To come seven years into an eight-year administration by an administration that is about to take its final bow is not necessarily as helpful to us as it should be because we are, a year from now, we are in fact, less than a year from now, we are going to swear in a new administration that will tool up and have its own views on these things.

So while I think it is helpful to have a policy document on the table that has got more clarity and more forward look to it, it comes awfully late in the game, and I think it will be one of several things that gets looked at. But we are way out of sequence in terms of being able to take that in a meaningful way with this administration, I think, and do much with it.

We are going to try to do what we can with it in this committee, but I think nobody should fool themselves about exactly the way the cards sit. We need a full blown debate on what our space future should be, and these policy recommendations which have now been forthcoming are a useful part of that debate, but they are not the end of the debate. In a sense, they are the beginning of the debate. So we will certainly welcome your thoughts, the thoughts of your group and others that now want to get into a serious assessment of what American space policy for the future should be.

Mr. PARMET. My own immediate view is better now than wait until the new administration comes in. At least you get a start on what might be the skeleton for a policy.

Senator RIEGLE. I would agree with that, Mr. Parmet. I am just saying we are seven years late, and that is a little troubling.

Mr. PARMET. I agree with that.

In the commercial world—I will slip back to that—every big company has its own corporate policies, and if they have a change in administration, the policies are still there, and they are flexible enough to meet new conditions. If they are basically correct, then a new administration can redirect them and further develop them. I do not think we should wait until after the elections to start this. But I agree with you that it requires a lot of "look-see" before it is adopted.

One final point that I would like to make concerns the annual budget hassle. NASA always seems to have a problem, whether they admit it or not, and part of that problem can be laid at their own doorstep. They frequently underestimate what the cost of a major project is in order to get it going and then believe they will catch up later. I think it ought to be laid out up front, and at the same time I recognize that it is a political situation, and I am not very good at that.

It is difficult to do a good job while minimizing costs if you do not know from one year to the next what appropriations are going to be approved.

Finally, there is far too much micromanagement occurring from all sides. NASA needs oversight, to be sure, but it does not need as much as it is getting.

With that, I will conclude my remarks and if you have any further questions, I will try to field them.

[The statement and questions and answers follow:]

STATEMENT

OF

MR. NORMAN R. PARMET
DEPUTY CHAIRMAN
AEROSPACE SAFETY ADVISORY PANEL

before the

Subcommittee on Science, Technology, and Space
Committee on Commerce, Science and Transportation
United States Senate

Mr. Chairman and Distinguished Members of the Subcommittee:

The Aerospace Safety Advisory Panel will be presenting its annual report to the NASA Administrator and his senior managers during the Panel's statutory annual meeting on March 16, 1988, at NASA Headquarters. This report covers our work from February 1987 to February 1988.

Today I will discuss the Panel's views regarding the many and varied activities underway by NASA and its contractors leading to the next Space Shuttle mission (STS-26). The comprehensive strategy and major actions were defined basically in Admiral Truly's memorandum of March 24, 1986, "Strategy for Safely Returning the Space Shuttle to Flight Status."

> NASA . . . and its various contractors will use this guidance to proceed with the realistic, practical actions necessary to return to the NSTS flight schedule with emphasis on flight safety. This guidance is intended to direct planning for the first year of flight while putting into motion those activities required to establish a realistic and achievable launch rate that will be safely sustainable.

In effect, the Aerospace Safety Advisory Panel has been conducting its factfinding and reviews to assess those activities associated with Admiral Truly's stated strategy; especially as they affect flight safety.

The Panel's oft stated "safety first, schedule second" has been taken very seriously by NASA and its contractors as evidenced by many actions over the past year, e.g., the addition of an extra solid rocket motor test firing before launch of STS-26 as a result of an anomaly found on Development Motor No. 9 (DM-9) after completion of its full duration firing.

There is, however, another side to the "safety first, schedule second" coin. Space missions are inherently riskier than

aircraft flights as we normally view them, and even more risky than research and development aircraft missions. Therefore, the assessment and management of risk remains as a most significant attribute of NASA and contractor management teams. This is where the revitalized and expanded NASA Safety, Reliability, Maintainability and Quality Assurance organization and its activities come into play. It is their job to assure proper and timely implementation of the many activities involved in the overall risk management process including Failure Mode and Effects Analysis (FMEA), Critical Item identification, Hazard Analysis, and where utilized, a retention rationale. To achieve more effective results, NASA needs to institute a priority system for such work.

Based on the Aerospace Safety Advisory Panel's reviews and factfinding, it is our belief that the current endeavors of NASA and its contractors will lead to Space Shuttle operations that are safer than those prior to the Challenger disaster. In support of the Panel's view, I offer the following: (this is not all inclusive).

- The SRM&QA organization at NASA Headquarters, NASA centers and the equivalent ones at Shuttle contractors are not "silent" as they contribute directly as participants with the Shuttle Program Office at Johnson Space Center (JSC) and Marshall Space Flight Center (MSFC) and the Shuttle Operations Office at Kennedy Space Center (KSC) day-to-day efforts as well as in the oversight of program risk management. Examples of this are their active participation in Level I, II, and III FMEA/CIL/HA meetings and reviews, the work of the System Safety Review Panel chaired by JSC with membership from all three OSF centers and Headquarters, the NASA Safety Reporting System and communications in general, initiation and implementation of significant problem reporting, trend analysis, and independent systems assessment capability.

- The continuing activities of the Propulsion Systems Integration Group which brings together NASA and contractor personnel to examine all efforts associated with the propulsion systems of the STS elements, i.e., Orbiter, External Tank, Solid Rocket Booster, Space Shuttle Main Engines, Group Support Operations, from design through test, checkout and launch processing and landing safety.

- Intercenter communications and between Level III and Level II (project to program to project) of the Space Transportation System have steadily improved over the past months as a result of a number of organization and management enhancements. Examples of this, in addition

to the Propulsion Systems Integration Group and other "systems" working groups, includes the assignment of astronauts to jobs that cut across center-to-center boundaries, Col. Charles Bolden to the MSFC SR&QA office, Col. Bryan O'Connor as head of the Space Flight Safety Panel, Capt. Bob Crippen as Deputy Director, NSTS Operations, located at KSC with his office.

- Certification of the hardware, software and procedures for the STS-26 mission include development testing and qualification testing. It is during these tests that one usually finds faults rather than during an actual mission, and this is the major reason for conducting such tests. Therefore, anomalies, failures and incidents which do not occur (particularly during development tests) should not be judged harshly but should be seen as part of the total certification program which is to assure that elements of the system and the system as a whole operate according to and within the bounds of the specifications. If we knew everything, there would be no need for such tests. The depth of the analyses and tests being performed prior to STS-26 on all significant components, functional subsystems and the systems gives added assurance that faults can be detected and corrected or sufficiently alleviated to maintain a reasonable and prudent risk level.

- NASA and contractor managements are sensitive to the need for and maintenance of an experienced and dedicated workforce. Where necessary support contractors have been brought onboard to aid the mainline work force. This includes individuals with special expertise and specialized small contractors, e.g., safety analysis and probabilistic risk assessments.

Activities at KSC, that is, hardware changes and modifications, test and checkout of the many functional systems on both flight and ground equipment, and the launch processing activities, were of particular interest to the Panel this year. The reason being, that KSC is at the end of the pipeline where everything comes together. A new organization as well as many new people in both the NASA and contractor workforce has really begun to "gel" as an effective and timely operation. Considering the vast array of supporting paper and paperwork which accompanies a normal mission, STS-26 involves a complete review of FMEA/CIL/HA's which includes the Operations and Maintenance Requirement Specifications (OMRSD's) and the Operational and Maintenance Instructions (OMI's) or procedures, for which the NASA and contractor resources are being stretched fairly thin. The recent change in launch date from June to August 1988 will certainly relieve this strain. It also means that additional vigilence is required to preclude additional non-mandatory hardware and

software changes from being processed simply because there is more time available for the "let's make it better" changes.

The Aerospace Safety Advisory Panel has always pushed for NASA and its contractors to make the most and best use of "lessons learned" from prior programs, from the current activities, and from any other source. We continue to urge this activity, which has been taken up by the SRM&QA organization at NASA Headquarters. NASA needs to take into account human factors during the design, development, test and operations associated with complex systems such as the Shuttle launch processing and overall Space Station design.

Our major concerns at this time regarding preparation for and the launch of STS-26 include the following:

- Solid Rocket Motor full duration firing with major manufacturing flaws (PVM-1). Types of flaws, predicated performance at these flaws, impact of not meeting predicted performance.

- Assurance that the retention rationale for items on the Critical Items List indicate the pros and cons in detail to assure that acceptance of waivers to these Critical Items is thoroughly documented.

- The qualification of the modified 17-inch liquid oxygen and liquid hydrogen shut-off/quick disconnect valves. The new design or modification to the basic design uses a latching device on a separately actuated shaft. Assurance that this latching device will actually hold the valve blade open throughout the ascent phase and not be the cause of any other problems is the issue.

- Landing/deceleration modifications, particularly anything adversely affecting the brakes at touchdown and rollout.

- Crew escape provisions during flight and ground rollout are still under study, which design, if any, will finally be used is unknown at this time.

- Use of human resources, particularly at the KSC and in the facilities used to check out the flight software. There is a history of long hours over long periods of time. It is good to have policies regarding this, it is even better to assure that there are few exceptions to that policy.

- The use of "freeze points" for STS-26 (and future missions) is an accepted management policy (which is not

> always implemented in practice). Program freeze points are established at specific intervals during flight processing. They are defined as those points in time when the cargo, integration hardware/software and flight design, vehicle flight hardware/software, crew activities/stowage and launch site flow design, definition, and content are complete. Subsequent to these points, only mandatory changes to the hardware, software or affected documentation will be permitted. Freeze point implementation is documented by the Level II Program Review and Control Board.

In summary, what the Aerospace Safety Advisory Panel has seen and heard over the past months tells us that a great deal has been accomplished in assuring the greatest degree of ground and flight safety commensurate with getting back into space which will always be a risk venture. There are a number of gates through which the Space Shuttle must pass before launch date in August, and with strict adherence to a prudent, practical safety program. This can be accomplished with less risks than that which existed prior to STS 51-L.

Mr. Chairman, on behalf of all the Aerospace Safety Advisory Panel members and consultants, I would like to thank you for the support we have received from this subcommittee. It has been our pleasure to be another set of "eyes" and "ears" for you in assuring that things prudent and reasonable are being done to make the first reflight of the Space Shuttle both safe and successful.

A final reminder, which the Panel has placed before NASA and the Congress in past years:

> The danger in placing undue reliance on an elaborate structure of review and oversight groups is that it can become a justification for not doing the job correctly in the first place. "Not to worry," says the manager to himself, "the reliability and quality assurance guys down the line will catch it."

QUESTIONS OF SENATOR PRESSLER AND THE ANSWERS

Question 1: Mr. Parmet, according to your statement, NASA needs to institute a priority system for the implementation of the activities involved in the over all risk management process.

How has the absence of such a priority system affected NASA's implementation of activities involved in its risk management process, and is it your observation that NASA intends to implement such a system?

What are the risks and problems associated with the continued absence of this priority system?

Answer 1: The absence of a priority system for the Critical Items List (CIL) and the Hazard Analyses (HA's) resulted in basically equal treatment for all CILs and HAs regardless of probability of occurrence and severity of occurrence. With limited resources and time it became evident that a means to set priorities would result in better products, a more orderly effort, and more timely products. This has been recognized by all concerned. NASA has been actively engaged in a multi-faceted approach to define a methodology applicable to the current activities focused on the next mission, STS-26, and to provide a detailed plan for the future. The NASA Headquarters Safety, Reliability, Maintainability and Quality Assurance has been in the forefront of this effort. Contractors have fully supported all of these activities as has NASA's senior management. Such a system is now in operation albeit at a low level. Without a priortization system excessive resource expenditures are inefficiently applied and may result in additional risk as well as possible late hardware and software modifications, and in some cases operational changes.

Question 2: Mr. Parmet, from the standpoint of the hardware changes and modifications, test and checkout of flight and ground systems, and launch processing activities, what does your Panel believe are the most significant threats to meeting the August launch, and what remain as the most challenging actions to be completed before this first launch?

Answer 2: First, Kennedy Space Center is the end of the "pipe-line" for all hardware and software that is to be flown and also that which supports the launch processing. With that in mind, the ability to close out all of the documentation that must preceed the launch (FMEA/CIL/HA's, OMRSD and OMI's) and the installation of the many mandatory modifications with their attendant tests and checkouts are clearly the most challenging actions to be completed prior to STS-26 launch. In line with this, the most significant threats to meeting the August launch date are the completion of qualification-for-flight tests on such items as the solid rocket motor, the 17-inch Liquid Oxygen and hydrogen ET/Orbiter disconnect valves, as well as the successful completion of the Flight Readiness Firing (FRF) in June. If the decision is made to install either of the two crew escape systems (rocket ejection, hatch-pole) the actual installation

and its testing and checkout will also be a significant "threat." A natural fallout from all of this is the use of overtime to meet these many demands. NASA and its contractors have developed appropriate policies to control overtime and these are being implemented at this time.

Question 3: Mr. Parmet, you have stated that NASA needs to take into account human factors during the design, development, test and operations associated with Shuttle launch processing.

Could you be more specific -- how might NASA improve its consideration of human factors associated with Shuttle launch processing, and to what extent has inadequate consideration of human factors affected NASA's Shuttle recovery effort?

Answer 3: The great complexity of the launch processing function requires a combination of highly trained, highly motivated, and reliable workers -- managers, engineers, technicians, quality assurance inspectors -- and reliable and easy to use data management systems. To meet these requirements NASA and its contractors have taken a number of steps over the past year to improve their consideration of human factors during the launch processing period at KSC and these actions are continuing. For example, NASA and the Shuttle Processing Contractor have clearly recognized previous shortcomings and are working hard to correct them. Discipline in carrying out work authorizations and job orders has been tightened. An improved worker safety program has been implemented by the SPC. Training opportunities have been expanded in some areas (although the quality of the instruction is not always satisfactory). Spare parts are more readily available when needed. Strict controls are in place regarding overtime.

The Aerospace Safety Advisory Panel recognizes and supports these positive steps. But it is equally necessary to point out another reality: the pressures and the problems of maintaining a desirable working environment will intensify dramatically as the launch date for STS-26 approaches. Thus the top management of NASA and the SPC needs to exercise continuing vigilance to see that a satisfactory working environment is maintained prior to STS-26 and for the flights that follow.

In the longer run, the issue of human resources is likely to grow more severe. In this regard, it is worth recalling the number of key retirements or departures that took place at NASA after the success of STS-1.

A specific program to examine possible sources of human error should be instituted as part of the NASA Safety, Reliability, Maintainability and Quality Assurance effort. Inital emphasis might profitably be placed on a study of potential design-induced human errors in the Space Transportation System.

Question 4: Mr. Parmet, in your statement you indicate that one of your Panel's major concerns is related to NASA's redesign or modification of the 17-inch disconnect valve.

Does your Panel have any reason to believe that NASA's modifications will not hold the valve blade open throughout the ascent phase of a launch? if so, what is the basis for this position?

Answer 4: Our concern with regard to the 17-inch disconnect valves, particularly the liquid oxygen valve due to the density of this fluid versus that of liquid hydrogen, is two-fold: first, this is a new design with many additional components and actions, secondly, the development and qualification test program will be the only "experience" with this new valve versus the much greater experience with the old valve. At this time, based on data currently available there is no solid reason to believe that the modified valve will not operate as designed. The test program should result in an understanding of the fluid flow characterisitics of the latching mechanism and the ability to not leak during steady-state and transient flow conditions. Further, it is our understanding that it is possible to reinstall the original valves if that beocmes necessary.

Question 5: Mr. Parmet, over the past several years, your Panel has expressed concern about the Shuttle's brake system, a concern that was reiterated by the Rogers Commission.

What is your Panel's assessment of NASA's long-term plan to implement its carbon brake design, and what are the relative risks and improvements associated with the interim brake development plan?

Answer 5: The NASA long-term plan (now underway) to upgrade the Orbiter brake system meets the Panel's long soughtafter modifications. The implementation of structural carbon in place of berylium is proceeding at the B. F. Goodrich company with planned tests at Wright-Patterson Air Force Base dynamometer facility with certification expected by the end of this year. The carbon brakes are expected to increase braking capability by about 50% during the abort situation. The interim brake development plan will most certainly increase safety margins for the STS-26 mission and the landing at Edwards Air Force site will be further insurance. Such modifications as stiffer landing gear axles, thicker brake stators, nose-wheel steering will reduce risks by reducing stresses on brake components and providing greater energy absorption as well. A final comment, upgrading the Orbiter brake system should not have taken as long as it has, such delays in doing what has to be done only leads to inefficient use of resources.

Senator RIEGLE. Thank you, Mr. Parmet.

Let me ask you some questions similar to what I put to Dr. Stever.

As you look at this countdown now, and this tentative date, the scheduled date of launch of August 4, do you feel comfortable that the problems that are there that have been identified and that are being worked to solution can be handled within that period of time?

Mr. PARMET. I would answer that by saying it is a success oriented program. You have heard the words before. It means if you drop a pencil and you bend to pick it up, you have lost time that you do not have.

If every test is successful from now on, then maybe the August date is valid. I would not hang my hat on it, though. But I think the important thing, as everybody else has underlined today, is safety first and schedule second. We even had some pins made up to wear to emphasize that when we go to meetings.

Senator RIEGLE. Is it fair to say that you and your panel are finding that you are able to participate fully and meaningfully in terms of the kind of independent view that you are giving here?

Mr. PARMET. First of all, I would like to say that NASA has been totally open with us, especially in the last couple years, and wherever we want to go, whatever we want to look at, they lay the cards on the table.

I cannot say that that was completely true prior to the Challenger accident because we were surprised by some of the things that we had not learned about. We cannot know everything, and I do not expect NASA to tell us everything, but in the areas where we feel we want to look they leave the door fully open for us to explore to whatever depth we can cover it.

Senator RIEGLE. Does your panel feel that any of the particular issues that have been raised today, the unresolved problems or the problems that are in the process of being solved, is there anything of extraordinary concern to your group that needs to be highlighted at this point?

Mr. PARMET. Well, we are in agreement with Dr. Stever. Our member on his panel is in full agreement with what Dr. Stever said today. So as far as we are concerned, we do not see any reason why the next flight should not go off.

Senator RIEGLE. And in the event that something arises that your panel is deeply concerned about, I take it that you will not hesitate to take that message to NASA and to the rest of us that have responsibilities in this area.

Mr. PARMET. We have direct access to Dr. Fletcher and his immediate staff and have never had any problems. When we have had concerns of this sort, we bring it directly to the people involved first. If we can get it resolved at the working level, that is always best. If we cannot, then we try to push it up toward the top.

Senator RIEGLE. Well, we are not interested in problems that do not exist but if a problem in this area does exist as we get closer and it is not resolved in that fashion, we can expect to hear from you I assume.

Mr. PARMET. You sure would.

Senator RIEGLE. Very good.

I think the record should note that Mr. Aldrich and Mr. Thompson both remained today in the committee room to hear your comments, and I think that is appropriate and should be acknowledged. Commander Hauck would have remained, but he had something else that he had to fly to and attend.

We will keep the record of the hearing today open for a week for Members to include any statements. We will be submitting additional questions for the record to you gentlemen and to the earlier witnesses.

I think this has been a very good hearing today. I think we can take some measure of confidence of the fact that able people are hard at work. They are representing I think the best traditions of our country in terms of rising to an extraordinary level of effort under difficult conditions to get a job done, and I want to just conclude by saying to the extent that NASA employees that are out there, direct or indirect, any part of that 100,000 plus Americans who are working on parts of this shuttle and subsequent shuttles, or those that are directly involved with major assignments and responsibilities in the shuttle program, that the

country appreciates the effort that is being made. We know this is not easy, and we know it is being done under extraordinary conditions of tension and scrutiny and pressure. And we appreciate the commitment of the people that are involved. We appreciate that work for the country. This is being done in behalf of the country and in the name of all the people of our country.

So that effort is appreciated. It has been a remarkable record over now 25 years, and we are counting on a return to successful and safe flight, and I think in due course we will see that.

The committee stands in recess.

[Whereupon, at 11:45 p.m., the subcommittee recessed.]

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